DTU Library

Calibration of surface roughness standards

Thalmann, R.; Nicolet, A.; Meli, F.; Picotto, G. B.; Matus, M.; Carcedo, L.; Hemming, B.; Ganioglu, O.; De Chiffre, Leonardo; Saraiva, F.

Total number of authors:
19

Published in:
Metrologia

Link to article, DOI:
10.1088/0026-1394/53/1A/04001

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Key Comparison EURAMET.L-K8.2013

Calibration of surface roughness standards

EURAMET project #1245

Final report

Rudolf Thalmann (METAS),

Anaïs Nicolet (METAS), Felix Meli (METAS), Gian Bartolo Picotto (INRIM), Michael Matus (BEV), Laura Carcedo (CEM), Antti Lassila (MIKES), Okhan Ganioglu (UME), Leonardo De Chiffre (DTU-CGM), Fernanda Saraiva (IPQ), Sten Bergstrand (SP), Slobodan Zelenika (DMDM), Anusorn Tonmueanwai (NIMT), Chin-Lung Tsai (CMS/ITRI), Wang Shihua (NMC/A*STAR), Oelof Kruger (NMISA), Marcos Motta de Souza (INMETRO), José Antonio Salgado (LNE), Zbigniew Ramotowski (GUM)

Wabern, October 2015

Contents

1 Document control

Version Draft B.1	Issued on April 2015.
Version Draft B.2	Issued on June 2015, comments participants taken in to account.
Version Draft B.3	Issued on August 2015, minor typos and comment in section 8.7.
Version Draft B.4	Issued on September 2015, minor editorial change.
Final report	Issued on October 2015, taking into account comments from CCL WG-MRA reviewers

2 Introduction

The metrological equivalence of national measurement standards and of calibration certificates issued by national metrology institutes is established by a set of key and supplementary comparisons chosen and organized by the Consultative Committees of the CIPM or by the regional metrology organizations in collaboration with the Consultative Committees.

At its meeting in October 2012, the EURAMET Technical Committee for length, EURAMET-TCL, decided upon a key comparison on the calibration of surface roughness standards, named EURAMET.L-K8.2013, with METAS as the pilot laboratory. The comparison was registered in January 2013, measurements were made between February 2013 and February 2015. The protocol followed the instructions of the preceding comparison EURAMET.L-K8 [1] as closely as possible.

3 Organization

3.1 Participants

Table 1. List of participant laboratories and their contacts.

Laboratory Code	Contact person, Laboratory	Phone, Fax, email
METAS (Pilot)	Ruedi Thalmann Federal Institute of Metrology METAS Lindenweg 50 CH-3003-Bern-Wabern Switzerland	Tel. +41 58 387 03 85 Fax +41 58 387 02 10 e-mail: rudolf.thalmann@metas.ch
LNE	José Antonio Salgado LNE Laboratoire national de métrologie et d'essais 1, rue Gaston Boissier F-75015 Paris France	Tel. +33 1 40 43 3777 Fax +33 1 40 43 3737 e-mail: Jose.Salgado@lne.fr
INRIM	Gian Bartolo Picotto Istituto Nazionale di Ricerca Metrologica Strade delle Cacce, 91, 10135 Torino Italy	Tel : 39 11 3919 969 or 973 Fax : 39 11 3919 959 e-mail : g.picotto@inrim.it
BEV	Michael Matus Bundesamt für Eich- und Vermessungswesen BEV Arltgasse 35 A-1160 Wien Austria	Tel. +43 1 21110 6540 Fax +43 1 21110 6000 e-mail: michael.matus@bev.gv.at
CEM	Laura Carcedo Head of the Surface Quality Laboratory Length Area CENTRO ESPAÑOL DE METROLOGÍA	Tel. +34 918074716 Fax +34 918074807 e-mail: lcarcedo@cem.minetur.es

	Alfar, 2 - Tres Cantos 28760 Madrid Spain	
MIKES	Antti Lassila Mittatekniikan keskus - Centre for Metrology and Accreditation (MIKES) P.O. box 9 (Tekniikantie 1) FIN-02151 Espoo Finland	Tel: +358 2950 54413 GSM: +358 40 7678584 Fax: +358 2950 54 499 e-mail: Antti.Lassila@mikes.fi
UME	Okhan Ganioglu TÜBİTAK UME Ulusal Metroloji Enstitüsü TÜBİTAK Gebze Yerleşkesi Barış Mah. Dr.Zeki Acar Cad. No:1 41470 Gebze / Kocaeli Turkey	Tel : +90 262 679 50 00 (ext. 5300) Fax : +90 262 679 50 01 e-mail : okhan.ganioglu@tubitak.gov.tr
DTU-CGM	Leonardo De Chiffre DTU Mekanik – CGM Produktionstorvet 427A DK-2800 Kgs. Lyngby Denmark	Tel. +45 45 25 47 60 Fax +45 45 93 01 90 e-mail: ldch@mek.dtu.dk
GUM	Zbigniew Ramotowski Central Office of Measures (GUM) Director of Length & Angle Department ul. Elektoralna 2 00-139 Warszawa Poland	Tel.: +48 22 581 95 43 Fax: +48 22 620 83 78 e-mail: length@gum.gov.pl
IPQ	Fernanda Saraiva Instituto Português da Qualidade Rua António Gião, 2 2829-513 CAPARICA Portugal	Tel: + 351 21 2948160 Fax: + 351 21 2848188 e-mail: fsaraiva@ipq.pt
SP	Sten Bergstrand SP Technical Research Institute of Sweden Measurement Technology Box 857 SE-501 15 Borås Sweden	Tel. +46 10 516 57 73 Fax +46 10 516 56 20 e-mail: sten.bergstrand@sp.se
DMDM	Slobodan Zelenika Directorate of Measures and Precious Metals Mike Alasa 14 11000 Belgrade Serbia	Tel : +381112024421 Fax : +381112181668 e-mail: zelenika@dmdm.rs
NIMT	Anusorn Tonmueanwai Dimensional Metrology Department National Institute of Metrology Thailand 3 / 4-5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120 Thailand	Tel : +662 5775100 ext 1202 Fax : +662 5775088 e-mail: anusorn@nimt.or.th
CMS/ITRI	Chin-Lung Tsai (Walter Tsai) CMS/ITRI Bldg. 16, No. 321, Sec. 2, Kuang Fu Rd. Hsinchu city 30011 Taiwan (R.O.C.)	Tel: +886 3 5743764 Fax: +886 3 5726445 e-mail: Walter_Tsai@itri.org.tw
NMC/ A*STAR	Wang Shihua NMC/A*STAR	Tel : 6279 1941 Fax : 6279 1992

	1 Science Park Drive Singapore 118221 Singapore	e-mail: wang_shihua@nmc.a-star.edu.sg
NMISA	Oelof Kruger Bld 5 CSIR campus Meiring Naude road, Brumeria Pretoria South Africa	Tel : + 27 12 841 4340 Fax : + 27 12 841 4458 e-mail: oakruger@nmisa.org
INMETRO	Marcos Motta de Souza Dimensional Metrology Laboratory INMETRO - National Institute of Metrology Quality and Technology Av. N.Sra. das Graças, 50 Xérem, Duque de Caxias, RJ. Brazil	Tel. +55 21 2679 9726 Fax +55 21 2679 9597 e-mail: mmsouza@inmetro.gov.br

3.2 Schedule

Details of the planned and actual schedules as well as date of receipt of results from the participants are shown in Table 2. The MRA states that the results should be sent within six weeks of completing the measurements.

Table 2. Schedule of the comparison.

RMO	Laboratory	Planned date of measurement	Actual date of measurement	Results received
EURAMET	METAS	Mar 2013	Feb 2013	11.03.2013
	DTU-CGM	Apr 2013	Apr 2013	14.08.2013
	MIKES	May 2013	May 2013	21.06.2013
	IPQ	Jun 2013	Jun 2013	08.08.2013
	BEV	July 2013	Jul 2013	06.09.2013
	SP	Aug 2013	Aug 2013	18.10.2013
	INRIM	Sep 2013	Sep 2013	18.04.2014
	LNE	Oct 2013	Oct 2013	11.04.2014
	CEM	Nov 2013	Nov 2013	04.09.2014
	GUM	Dec 2013	Dec 2013	31.01.2014
	METAS	Jan 2014	Jan 2014 (stability check)	13.01.2014
	DMDM	Feb 2013	Feb 2014	13.08.2014
	UME	Mar 2013	Mar 2014	27.05.2014
APMP	NIMT	Apr 2013	Apr 2014	06.06.2014
	NMC/A*STAR	May 2014	May 2014	03.10.2014
	CMS/ITRI	Jun 2014	Jun 2014	17.10.2014
AFRIMETS	NMISA	Jul 2014	Dec 2014	10.02.2015
SIM	INMETRO	Aug 2014	Aug 2014	08.12.2014
EURAMET	METAS	Sep 2014	Feb 2015 (stability check)	10.02.2015

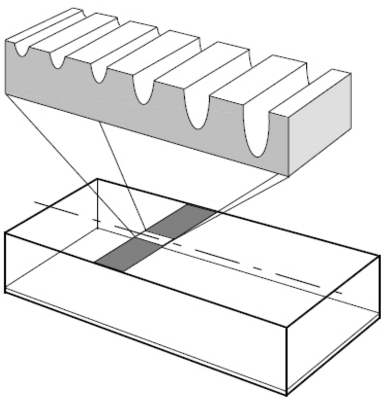
The original schedule has been changed in the course of the comparison, mainly due to the requirement, that participants after January 2014 needed an ATA carnet and because NMISA was not ready with their equipment in the time slot originally allocated. There were no major transportation or customs problems, except import/export to and from Brazil, which took much more time. This didn't delay the comparison, since they were scheduled at the end of the circulation.

4 Artefacts

Five standards were circulated: one type A2, two type C1 and two type D1 according to ISO 5436-1 [2]. The standards were from different manufacturers and different materials. A plastic case (40 cm x 32 cm x 17 cm) containing 4 wooden boxes with the artefacts and the technical protocol was used for transportation (Figure 1).

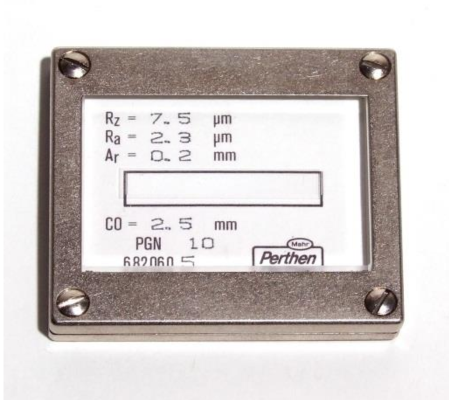
Figure 1. Transporting case.

4.1 Type A2 standard



Depth measurement standard, KNT 2060/01, S/N 0589606
Manufacturer: Halle, material: glass
6 grooves with rounded bottoms,
nominal values *d* 0.33 µm to 8.93 µm

4.2 Type C1 standard

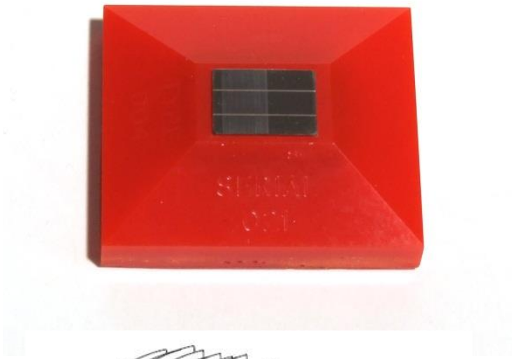


Spacing measurement standard, PGN 10, no 682060 5
Manufacturer: Perthen, material: glass
sine wave profile,
nominal values *Ra* 2.3 µm, *RSm* 200 µm

4.3 Type D1 standard

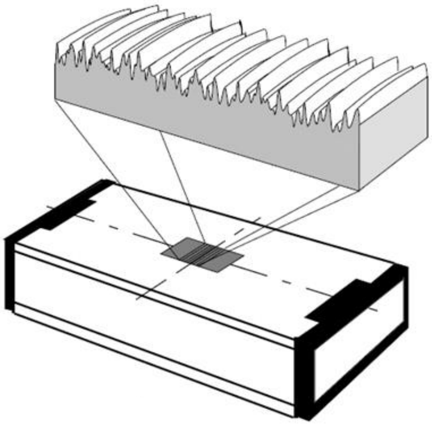
Roughness measurement standard, type 004, S/N 021
Manufacturer: Rubert, material: electroformed metal,
unidirectional irregular profile,
nominal values *Ra* 0.15 µm

Measurement area: Between the two marking lines.



4.4 Type D1 standard

Roughness measurement standard, KNT 2070/03, S/N 0986
Manufacturer: Halle, material: hard nickel plate
unidirectional irregular profile,
nominal values *Ra* 0.06 µm



http://www.halle-normale.de/pdf/2011/englisch/06_KNT-4058_Te
normale.de/pdf/2011/englisch/15_Ps-KNT-4070__Bl_6-1_GB.pdf

4.5 Additional type C1 standard

Spacing measurement standard, NIST SRM 2072, S/N 1015
Manufacturer: NIST, material: steel
sine wave profile,
nominal values *Ra* 1 µm, *RSm* 100 µm

4.6 Type F1 Reference data (softgauge)

Two softgauges in 7-bit ASCII character code (*.smd format) according to ISO 5436-2 were included in a memory stick to investigate software algorithms independently of hardware variation:

METAS_Aperiodic.smd: Aperiodic profile
METAS_Periodic.smd: Periodic profile

The two data files correspond to primary profiles, i.e. after removal of form but before λs filtering. For laboratories not able to deal with the *.smd format, also files in *.prf format were available. The *.prf format files were kindly transformed by LNE from the *.smd format files.

5 Measuring instructions

5.1 Measurands

The following parameters were to be determined:

Artefact	**Parameters**	**Relevant standards**
Type A2 KNT 2060/01	*d, Pt*	ISO 5436-1 [2] ISO 4287 [3]
Type C1 PGN 10	*Ra, Rq, Rz, Rt, RSm*	ISO 5436-1 ISO 4287
Type D1 S/N 021	*Ra, Rq, Rz, Rt*	ISO 5436-1 ISO 4287
Type D1 KNT 2070/03	*Ra, Rq, Rz, Rt*	ISO 5436-1 ISO 4287
Type C1 SRM 2072	*Ra, Rq, Rz, Rt, RSm*	ISO 5436-1 ISO 4287
Type F1	*Ra, Rq, Rz, Rt, Rsk, (RSm)*	ISO 5436-2 ISO 4287

For each parameter, its value and the observed standard deviation σ had to be reported.

5.2 Measurement and evaluation for type A2 artefact

A least squares mean line representing the upper level is drawn over the groove. A least squares circle is fitted through the centre third of the width of the groove. The depth *d* is evaluated from the line to the lowest point of the fitted circle (see Figure 2). The portions to be used for the evaluation are those shown at A, B and C in Figure 2. The average of five traces, evenly distributed over the measuring window, together with the standard deviation σ were to be reported.

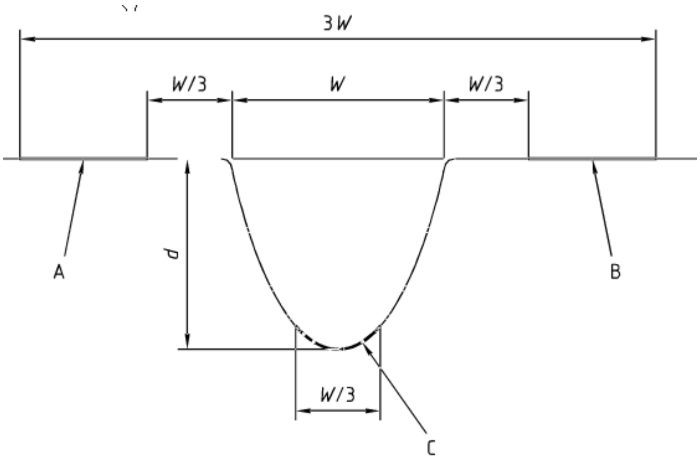


Figure 2. Assessment of the depth measurement standard (ISO 5436-1).

Note, that the laboratories were also asked to determine *Pt* (see table in 5.1). However, since *d* is the standardized measurand for type A2 standards according to ISO 5436-1 and all laboratories were able to determine *d*, the *Pt* results are not reported here because they would provide essentially redundant information. They were, however, included in the results spreadsheet distributed to the participants.

5.3 Measurement conditions for type C1 and D1 artefacts

The average of twelve traces, evenly distributed over the measuring window, together with the standard deviation σ were to be reported. A Gaussian filter according to ISO 16610-21:2011 had to be applied for evaluating the *R* parameters.

Standard	**Evaluation length (mm)**	λ_c **(µm)**	λ_s **(µm)**	**Measuring force (mN)**	**Sampling spacing (µm)**	**Tip radius (µm)**
Type C1 PGN 10	4.00	800	2.5	< 1	≤ 0.5	2
Type D1 S/N 021	4.00	800	2.5	< 1	≤ 0.5	2
Type D1 KNT 2070/03	1.25	250	2.5	< 1	≤ 0.5	2
Type C1 SRM 2072	4.00	800	2.5	< 1	≤ 0.5	2

5.4 Evaluation of type F1 reference data

The following evaluation parameters were to be respected:

Standard	**File name**	**Evaluation length (mm)**	λ_c **(µm)**	λ_s **(µm)**	**Parameters**
F1 aperiodic	METAS_Aperiodic.smd	1.25	250	2.5	*Ra, Rq, Rz, Rt, Rsk*
F1 periodic	METAS_Periodic.smd	4.00	800	2.5	*Ra, Rq, Rz, Rt, Rsk, RSm*

The total profile length is 7 cutoff lengths (7 λ_c). The evaluation length l_n was the five central sampling length $l_r = \lambda_c$, thus removing one cutoff length on each side in order to avoid end effects.

6 Stability of artefacts

6.1 Stability measurements

METAS measured the samples in February 2013, in January 2014 and in February 2015, i.e. at the beginning, in the middle and at the end of the comparison. Note that only the first result in February 2013 accounts for the key comparison, the other two were to monitor the stability of the samples. For simplicity, the evaluation of these measurement data was done in the same way as for the participant's results, i.e. the deviation from the weighted mean and the E_n values were calculated for each parameter and each standard.

Table 3 shows the results of the stability measurements carried out by the pilot laboratory, where the "reference value" x_{ref} is the weighted mean of the three results x_i. All E_n values are smaller than 0.5, which can be interpreted that there is no significant change within the uncertainty.

Table 3. Results of stability measurements by the pilot laboratory.

Parameter	Period	x_i / µm	u_i / µm	$(x_i - x_{ref})$/µm	$U(x_i - x_{ref})$/µm	E_n
Type A2, KNT 2060/01, S/N 0589606						
R1, *d*	Feb 2013	0.317	0.010	-0.002	0.016	0.12
	Jan 2014	0.315	0.011	-0.004	0.019	0.21
	Feb 2015	0.324	0.010	0.005	0.016	0.32
R2, *d*	Feb 2013	0.405	0.011	-0.001	0.017	0.05
	Jan 2014	0.407	0.011	0.001	0.017	0.07
	Feb 2015	0.405	0.016	-0.001	0.029	0.03
R3, *d*	Feb 2013	1.343	0.011	0.001	0.019	0.06
	Jan 2014	1.344	0.010	0.002	0.016	0.13
	Feb 2015	1.339	0.010	-0.003	0.016	0.18
R4, *d*	Feb 2013	2.713	0.011	-0.003	0.018	0.17
	Jan 2014	2.723	0.012	0.007	0.020	0.35
	Feb 2015	2.713	0.011	-0.003	0.018	0.17
R5, *d*	Feb 2013	5.520	0.011	-0.004	0.018	0.22
	Jan 2014	5.533	0.012	0.009	0.020	0.45
	Feb 2015	5.520	0.011	-0.004	0.018	0.22
R6, *d*	Feb 2013	8.915	0.014	0.002	0.022	0.09
	Jan 2014	8.934	0.023	0.021	0.043	0.49
	Feb 2015	8.906	0.012	-0.007	0.017	0.42
Type C1, PGN 10, no 682060 5						
Ra	Feb 2013	2.372	0.018	0.000	0.029	0.01
	Jan 2014	2.368	0.018	-0.004	0.029	0.13
	Feb 2015	2.375	0.018	0.004	0.029	0.13
Rq	Feb 2013	2.660	0.020	0.002	0.032	0.05
	Jan 2014	2.654	0.021	-0.005	0.035	0.14
	Feb 2015	2.662	0.021	0.003	0.035	0.09
Rz	Feb 2013	7.705	0.063	0.021	0.102	0.21
	Jan 2014	7.663	0.063	-0.020	0.102	0.20
	Feb 2015	7.682	0.067	-0.001	0.112	0.01
Rt	Feb 2013	7.764	0.065	0.012	0.105	0.12
	Jan 2014	7.737	0.066	-0.015	0.108	0.14
	Feb 2015	7.754	0.068	0.002	0.112	0.02
RSm	Feb 2013	199.930	0.067	-0.055	0.109	0.50
	Jan 2014	199.990	0.067	0.005	0.109	0.05
	Feb 2015	200.033	0.067	0.049	0.109	0.45

Parameter	Period	x_i / µm	u_i / µm	(x_i-x_{ref})/µm	$U(x_i-x_{ref})$/µm	E_n
Type D1, S/N 021						
Ra	Feb 2013	0.126	0.003	0.002	0.005	0.43
	Jan 2014	0.124	0.003	0.000	0.005	0.03
	Feb 2015	0.122	0.003	-0.002	0.005	0.40
Rq	Feb 2013	0.159	0.003	0.002	0.005	0.31
	Jan 2014	0.157	0.003	0.000	0.005	0.04
	Feb 2015	0.155	0.003	-0.002	0.005	0.36
Rz	Feb 2013	1.056	0.039	0.009	0.064	0.14
	Jan 2014	1.060	0.038	0.013	0.062	0.20
	Feb 2015	1.027	0.037	-0.020	0.060	0.33
Rt	Feb 2013	1.220	0.050	0.030	0.085	0.36
	Jan 2014	1.184	0.043	-0.005	0.067	0.08
	Feb 2015	1.170	0.046	-0.020	0.075	0.26
Type D1, KNT 2070/03, S/N 0986						
Ra	Feb 2013	0.060	0.002	0.000	0.004	0.03
	Jan 2014	0.060	0.002	0.000	0.004	0.03
	Feb 2015	0.060	0.002	0.000	0.004	0.00
Rq	Feb 2013	0.075	0.002	0.000	0.004	0.01
	Jan 2014	0.075	0.002	0.000	0.004	0.02
	Feb 2015	0.075	0.002	0.000	0.004	0.01
Rz	Feb 2013	0.326	0.021	0.000	0.034	0.00
	Jan 2014	0.324	0.021	-0.002	0.034	0.06
	Feb 2015	0.328	0.021	0.002	0.034	0.06
Rt	Feb 2013	0.442	0.023	-0.001	0.038	0.04
	Jan 2014	0.444	0.023	0.001	0.037	0.02
	Feb 2015	0.444	0.023	0.001	0.037	0.02
Type C1, NIST SRM 2072, S/N 1015						
Ra	Feb 2013	1.010	0.010	-0.001	0.017	0.03
	Jan 2014	1.012	0.010	0.002	0.016	0.11
	Feb 2015	1.009	0.010	-0.001	0.016	0.08
Rq	Feb 2013	1.120	0.011	-0.001	0.018	0.06
	Jan 2014	1.124	0.011	0.003	0.017	0.15
	Feb 2015	1.120	0.011	-0.002	0.017	0.09
Rz	Feb 2013	3.350	0.090	-0.040	0.147	0.27
	Jan 2014	3.418	0.089	0.028	0.144	0.20
	Feb 2015	3.400	0.090	0.011	0.148	0.07
Rt	Feb 2013	3.370	0.090	-0.061	0.140	0.44
	Jan 2014	3.448	0.090	0.017	0.139	0.12
	Feb 2015	3.518	0.126	0.087	0.226	0.38
RSm	Feb 2013	101.658	0.063	0.044	0.097	0.45
	Jan 2014	101.600	0.060	-0.014	0.090	0.16
	Feb 2015	101.540	0.101	-0.074	0.186	0.40

For some of the parameters, the stability results are also represented graphically in Figure 3.

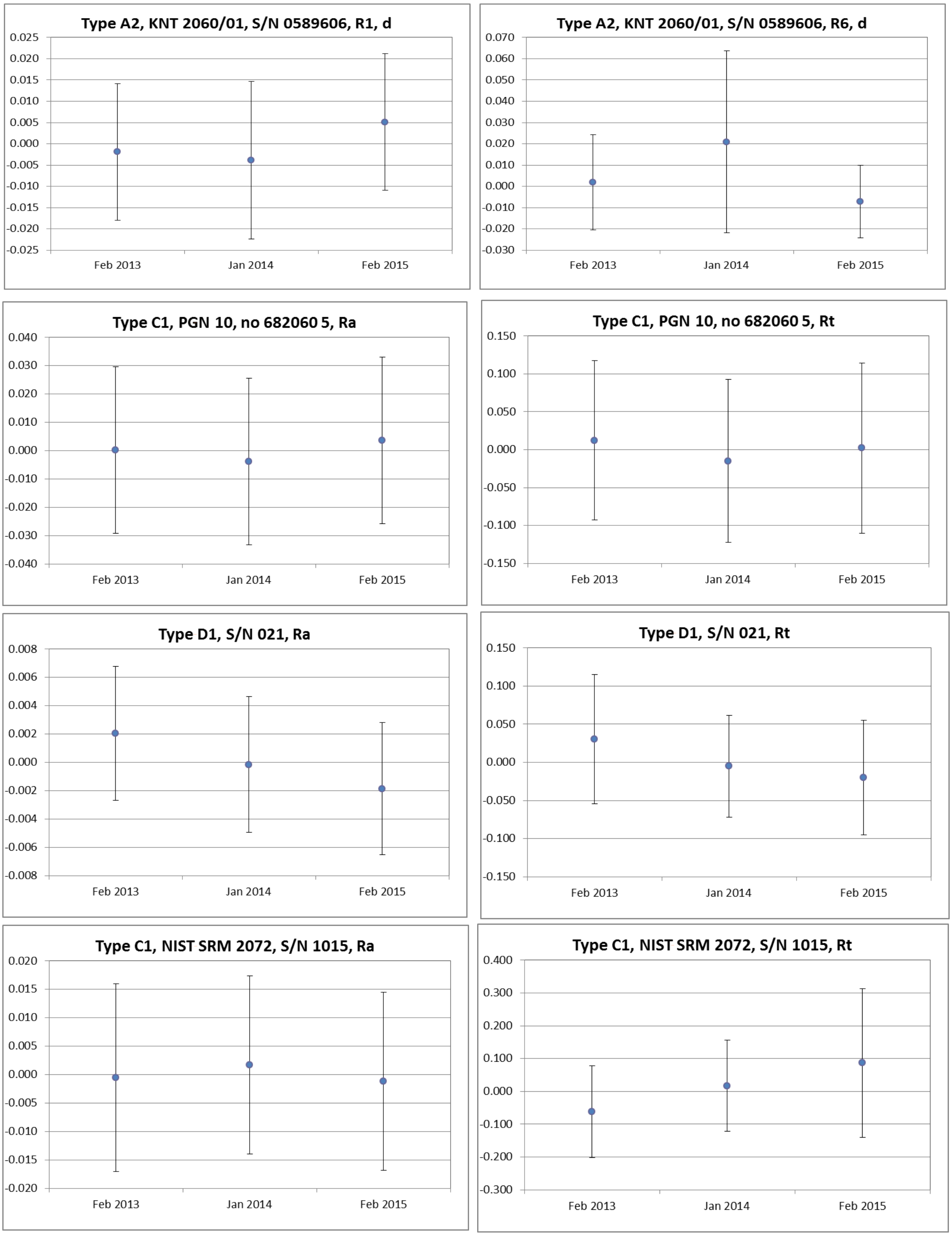


Figure 3. Stability measurements for selected standards and parameters (uncertainty bars for k = 2).

6.2 Condition of artefacts at the end of comparison

Several defects and damages on the standards were reported by the participants, already at an early stage of the comparison. The pilot did not try to identify the date and place, where the damages occurred. However, since the participants were free to choose the exact location of the measured profiles on the artefacts, there was always the possibility to choose a place more or less free of defects. In case a measurement was influenced by a surface defect, this accounts for the standard deviation and is therefore part of the measurement uncertainty. In Figure 4 to Figure 8, the status of the standards is documented as observed by the pilot at the end of the comparison.

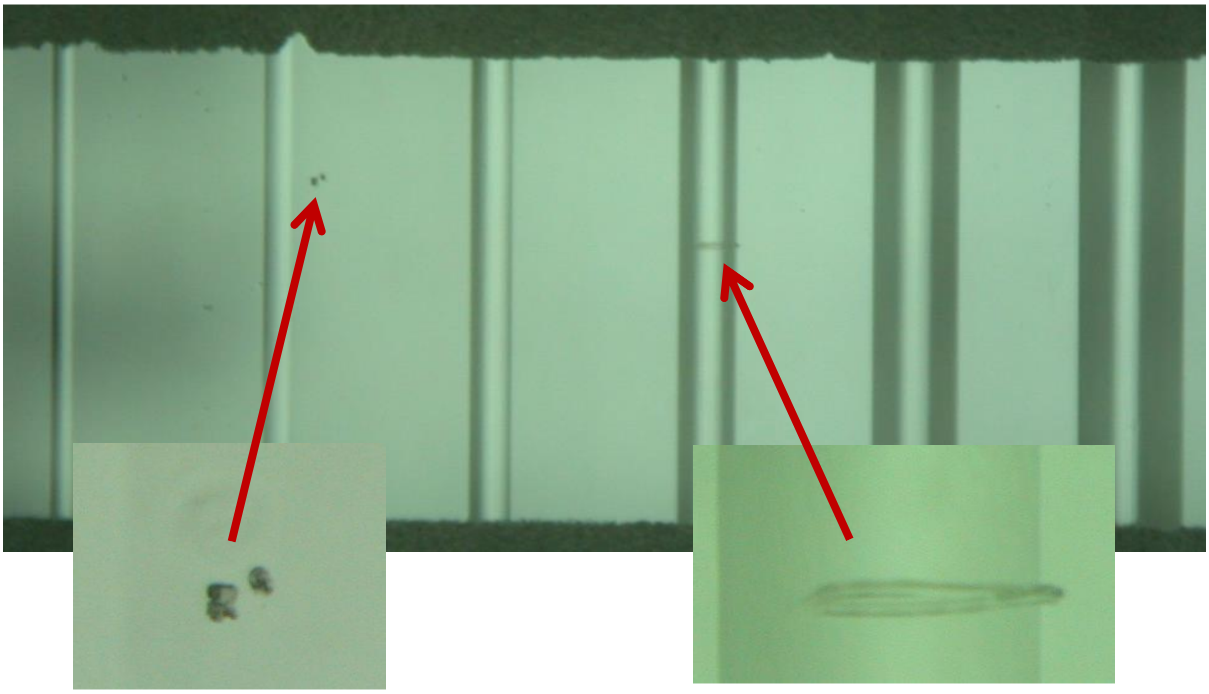


Figure 4. Defects on the standard Halle A2 KNT 2060/01.

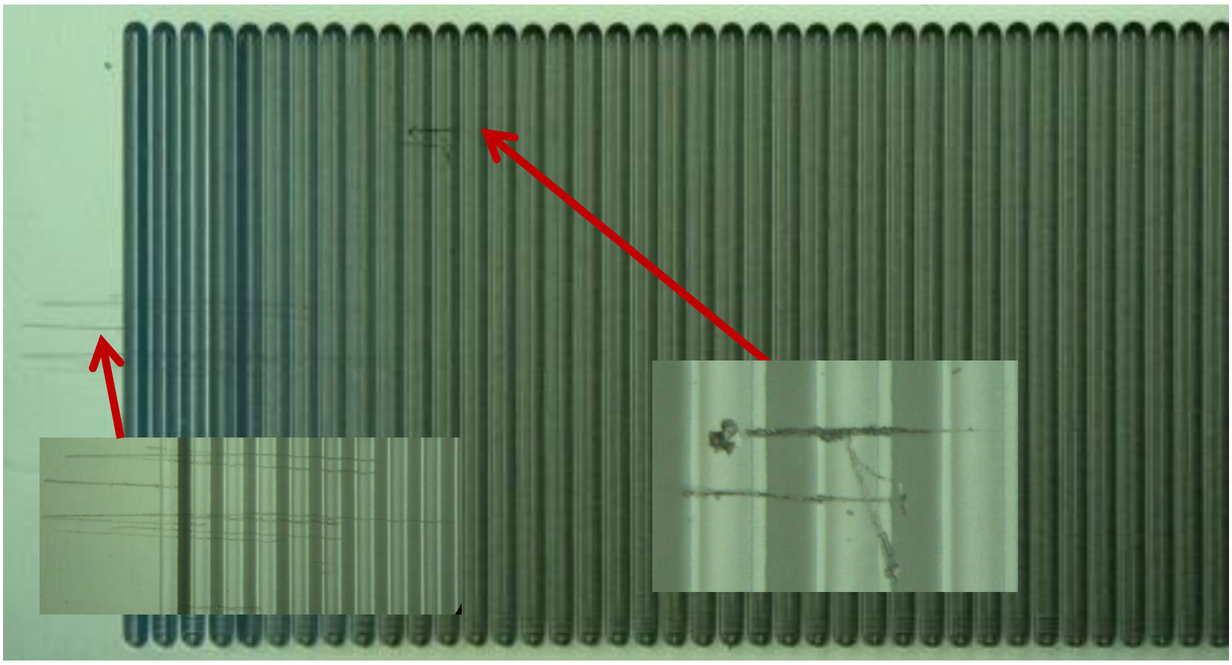


Figure 5. Defects on the standard Perthen C1 PGN 10.

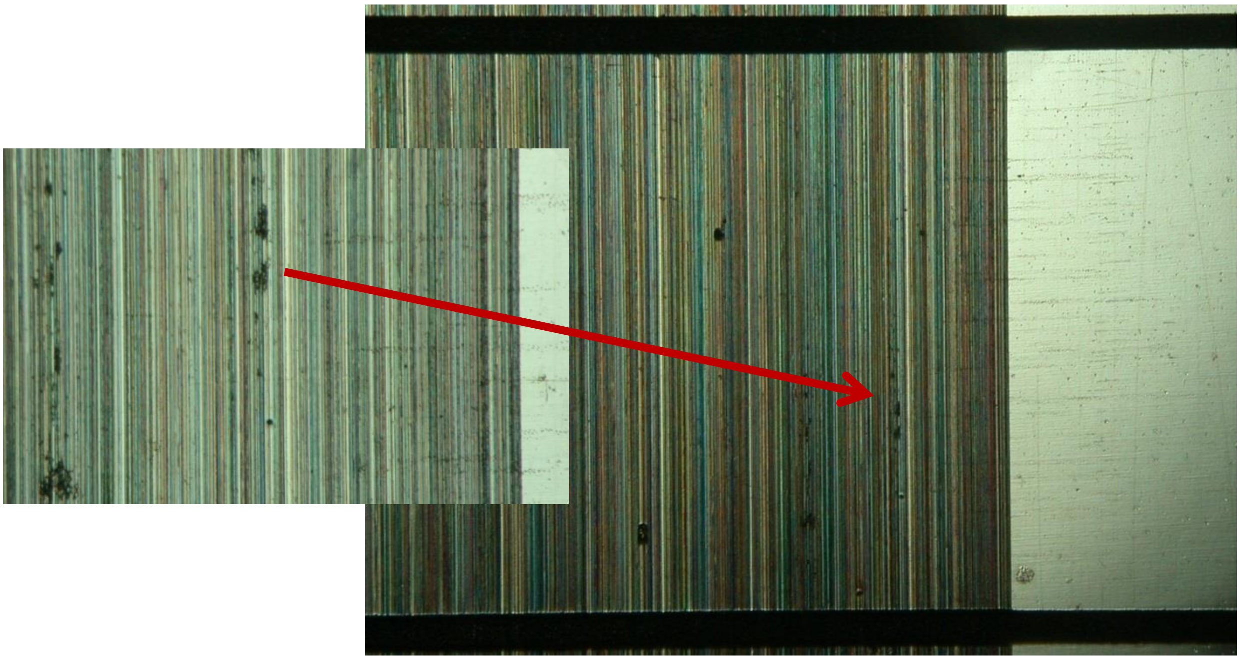


Figure 6. Defects on the standard Rubert D1 SN021.

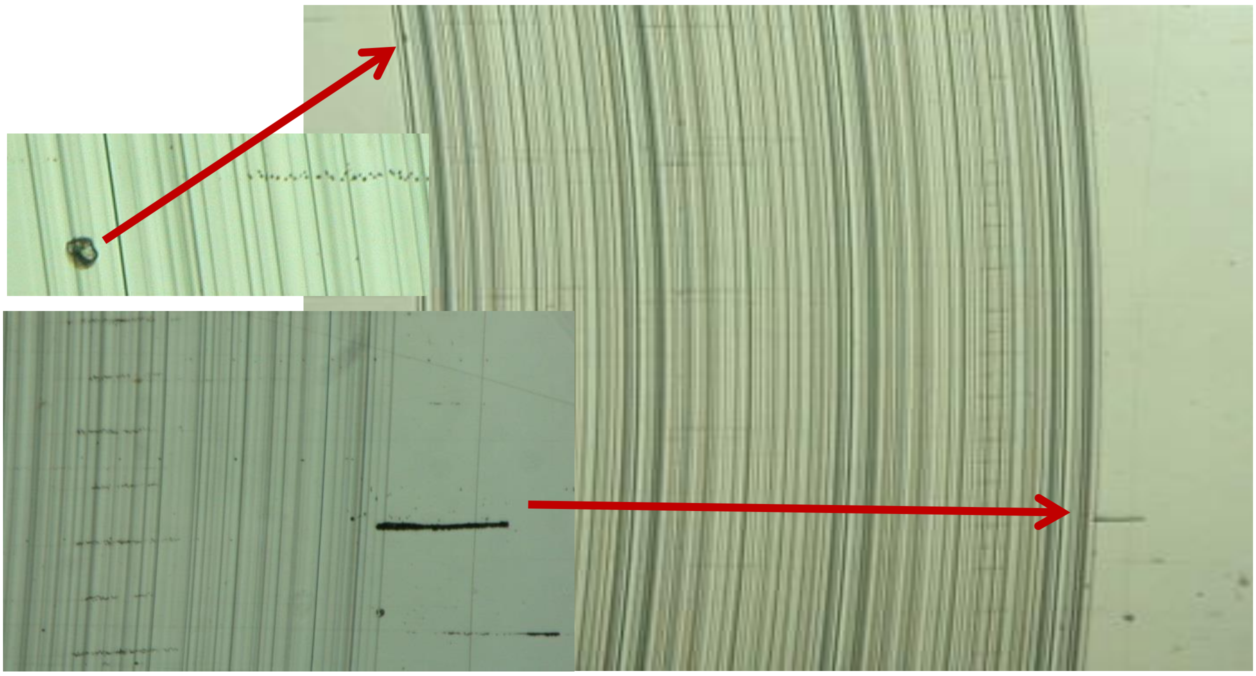


Figure 7. Defects on the standard Halle D1 KNT2070/03.

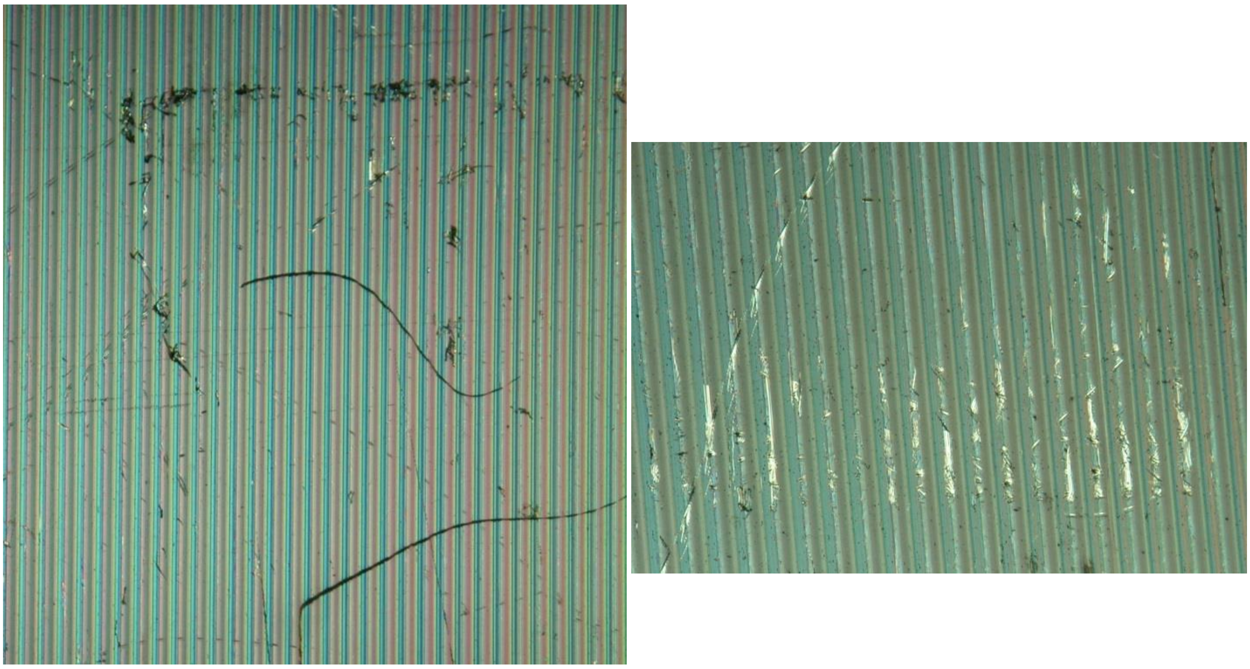


Figure 8. Two defects on the standard NIST C1 SRM 2072.

6.3 Description of the damages observed at the end of the comparison

Halle A2 KNT 2060/01

- Scratch on groove R4 (due to a stylus?)

Perthen C1 PGN 10

- Stylus scratches left in the middle
- Damage left above

Rubert D1 SN021

- Several stylus scratches
- 3 black spots
- dirty grooves

Halle D1 KNT2070/03

- Stylus scratches all over the surface
- Deep scratch on right side
- Round damage left above

NIST C1 SRM 2072

- Numerous damages and scratches all over the surface.

Note: The pilot did not photographically document the status of the surfaces at the beginning of the comparison. Some minor defects might have been present before the circulation of the standards.

7 Results

7.1 Results and standard uncertainties as reported by participants

The results had to be reported by the participants on Word forms in tables such as Table 4. These were all copied in an Excel spreadsheet *EURAMET.L-K8.2013-evaluation.xlsx*, which served as Draft A report of this comparison. The spread sheet allows for the evaluation of the reference values according to section 8.1 of this report, for the determination of the largest consistent subset and the degrees of equivalence. The results as they were reported by the participants are shown in section 8.2.

Table 4. Format of how the results had to be reported by the participants.

Parameter	Value (µm)	σ (µm)	u_C (nm)	ν_{eff}
Ra				
Rq				
Rz				
Rt				
RSm				

σ: standard deviation
u_c: standard uncertainty
ν_{eff}: number of effective degrees of freedom (if estimated)

8 Analysis of the measurement results

8.1 Calculation of the KCRV and of the Degrees of Equivalence

The Key Comparison Reference Values KCRV were calculated for each measurand using the weighted mean. To each result x_i a normalised weight w_i was attributed, given by:

$$w_i = C \cdot \frac{1}{[u(x_i)]^2} \tag{1}$$

where the normalising factor, C, is given by:

$$C = \frac{1}{\sum_{i=1}^{I} \left(\frac{1}{u(x_i)} \right)^2} \tag{2}$$

The weighted mean $\bar{x}_w$ is given by:

$$\bar{x}_w = \sum_{i=1}^{I} w_i \cdot x_i \tag{3}$$

and the uncertainty of the weighted mean is calculated by:

$$u(\bar{x}_w) = \sqrt{\frac{1}{\sum_{i=1}^{I} \left(\frac{1}{u(x_i)} \right)^2}} = \sqrt{C}\ . \tag{4}$$

After deriving the weighted mean and its associated standard uncertainty, the deviation of each laboratory's result from the weighted mean is determined simply as $x_i - \bar{x}_w$. The uncertainty of this deviation is calculated as a combination of the uncertainties of the result, $u(x_i)$, and the uncertainty of the weighted mean $u(\bar{x}_w)$. The uncertainty of the deviation from the weighted mean is given by

$$u(x_i - \bar{x}_w) = \sqrt{[u(x_i)]^2 - [u(\bar{x}_w)]^2} \ . \tag{5}$$

For the determination of the key comparison reference value KCRV, statistical consistency of the results contributing to the KCRV is required. A check for statistical consistency of the results with their associated uncertainties can be made by the so-called Birge ratio R_B which compares the observed spread of the results with the spread expected from the individual reported uncertainties.

The application of least squares algorithms and the χ^2-test leads to the Birge ratio

$$R_B = \frac{u_{ext}(\bar{x}_w)}{u(\bar{x}_w)} , \tag{6}$$

where $u_{ext}(\bar{x}_w)$ is the external standard deviation

$$u_{ext}(\bar{x}_w) = \sqrt{\frac{1}{(I-1)} \cdot \frac{\sum_{i=1}^{I} w_i (x_i - \bar{x}_w)^2}{\sum_{i=1}^{I} w_i}} \ . \tag{7}$$

The Birge ratio has an expectation value of R_B = 1, when considering standard uncertainties. For a coverage factor of k = 2, the expectation value is increased and the data in a comparison are consistent provided that

$$R_B < \sqrt{1 + \sqrt{8/(I-1)}} , \tag{8}$$

where I is the number of laboratories.

For each laboratory's result the E_n value is calculated, where E_n is defined as the ratio of the deviation from the weighted mean, divided by the expanded uncertainty of this deviation:

$$E_n = \frac{|x_i - \bar{x}_w|}{\sqrt{[U(x_i)]^2 - [U(\bar{x}_w)]^2}} \ . \tag{9}$$

If statistical consistency according to equation (8) is not given, the result with the largest E_n is identified and excluded from the reference value and R_B is calculated again. This process of excluding the result with the largest E_n from contributing to the weighted mean is iterated until statistical consistency is reached.

Because inconsistent results are no longer correlated with the weighted mean, when calculating their E_n value a positive sign is used in equation (5) and consequently in the denominator of equation (9):

$$E_n = \frac{|x_i - \bar{x}_w|}{\sqrt{[U(x_i)]^2 + [U(\bar{x}_w)]^2}} \quad \text{for results excluded from the KCRV.} \tag{10}$$

8.2 Results, Reference values and Degrees of Equivalence

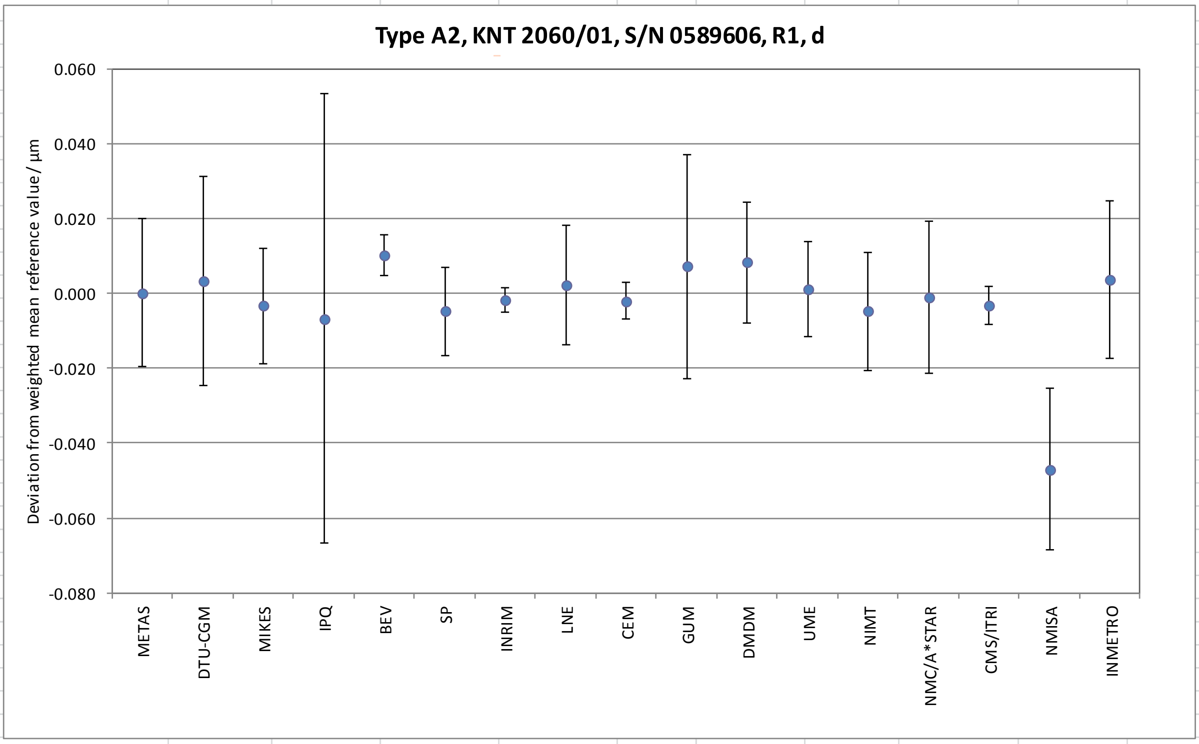
In the following, an extract of the Excel table *EURAMET.L-K8.2013-evaluation.xlsx* is given for each standard and each measurand. Laboratories starting with the largest E_n values were excluded (highlighted) until consistency according to the Birge ratio criterion was reached. E_n values larger than 1 are highlighted. Tables show final values of x_i and E_n for consistent Birge ratio R_B. All graphs show the deviations (x_i - x_w) from the weighted mean key comparison reference value in µm with uncertainties expanded with k = 2.

select gauge	1	Type A2, KNT 2060/01, S/N 0589606, R1, d	use 1 or 0 to in- or exclude	choose: k=2

Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	$(x_i - x_w)$/µm	k	$U(x_i - x_{ref})$/µm	E_n	w_i
METAS	0.317	0.003	0.010	118	1	0.000	2.00	0.020	0.01	0.01
DTU-CGM	0.320	0.005	0.014	10000	1	0.003	2.00	0.028	0.11	0.01
MIKES	0.313	0.004	0.008	9	1	-0.003	2.00	0.015	0.22	0.02
IPQ	0.310	0.001	0.030	108	1	-0.007	2.00	0.060	0.11	0.00
BEV	0.327	0.003	0.003	10000	1	0.010	2.00	0.006	1.84	0.14
SP	0.312	0.003	0.006	162	1	-0.005	2.00	0.012	0.41	0.04
INRIM	0.315	0.000	0.002	47	1	-0.002	2.00	0.003	0.55	0.32
LNE	0.319	0.010	0.008	35	1	0.002	2.00	0.016	0.14	0.02
CEM	0.315	0.003	0.003	10000	1	-0.002	2.00	0.005	0.41	0.18
GUM	0.324	0.004	0.015	15	1	0.007	2.00	0.030	0.24	0.01
DMDM	0.325	0.005	0.008	10000	1	0.008	2.00	0.016	0.50	0.02
UME	0.318	0.003	0.006	278	1	0.001	2.00	0.013	0.10	0.03
NIMT	0.312	0.003	0.008	5060	1	-0.005	2.00	0.016	0.30	0.02
NMC/A*STAR	0.316	0.004	0.010	10000	1	-0.001	2.00	0.020	0.05	0.01
CMS/ITRI	0.314	0.003	0.003	199	1	-0.003	2.00	0.005	0.61	0.16
NMISA	0.270	0.005	0.011	10000	0	-0.047	2.00	0.022	2.19	0.00
INMETRO	0.321	0.003	0.011	10000	1	0.004	2.00	0.021	0.18	0.01

	x_w	$u(x_w)$	ν_{eff}	$N - 1$	k_{ref}
Reference value	0.317	0.001	416	15	2.00
C	1.28E-06				

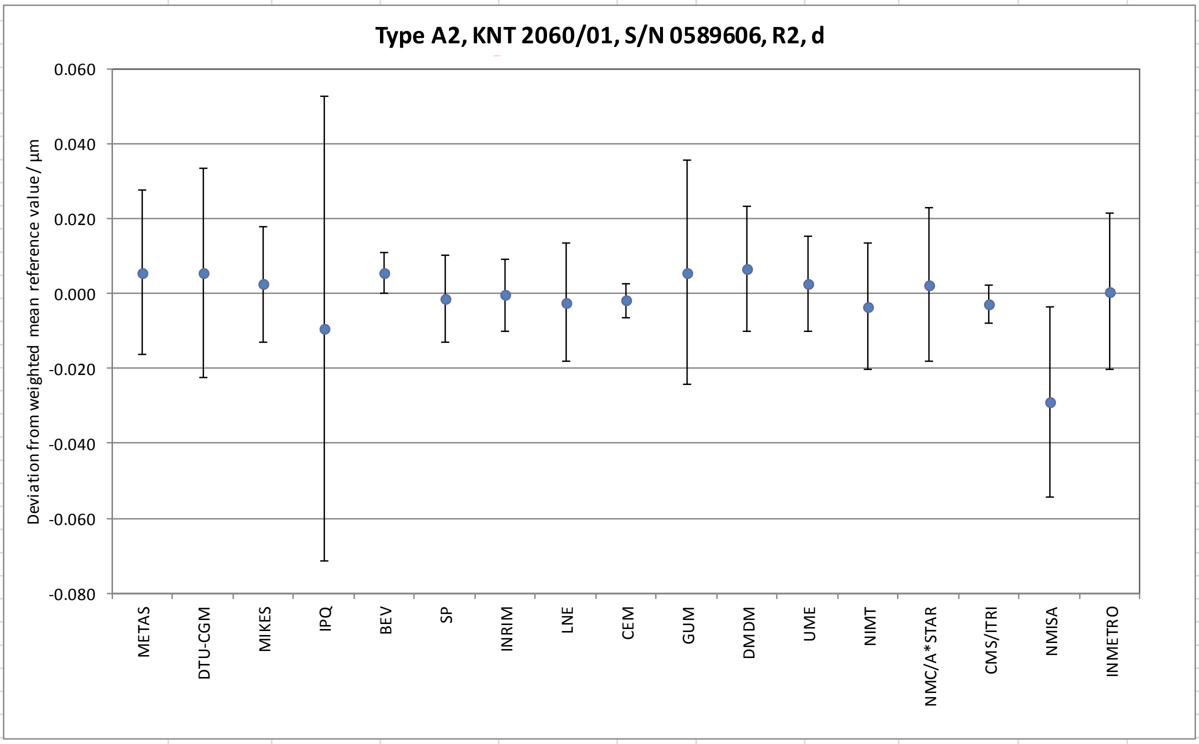
Consistency:		
u_{ext}	0.001	
R_B	1.062	Birge ok
Limit	1.315	



select gauge	2	Type A2, KNT 2060/01, S/N 0589606, R2, d			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	0.405	0.005	0.011	120	1	0.006	2.00	0.022	0.26	0.01
DTU-CGM	0.405	0.005	0.014	10000	1	0.006	2.00	0.028	0.20	0.01
MIKES	0.402	0.004	0.008	9	1	0.002	2.00	0.015	0.16	0.03
IPQ	0.390	0.003	0.031	110	1	-0.009	2.00	0.062	0.15	0.00
BEV	0.405	0.004	0.003	10000	1	0.006	2.00	0.005	1.04	0.20
SP	0.398	0.002	0.006	258	1	-0.001	2.00	0.012	0.12	0.05
INRIM	0.399	0.006	0.005	25	1	0.000	2.00	0.010	0.04	0.07
LNE	0.397	0.011	0.008	41	1	-0.002	2.00	0.016	0.15	0.03
CEM	0.398	0.002	0.003	10000	1	-0.002	2.00	0.005	0.42	0.25
GUM	0.405	0.003	0.015	15	1	0.006	2.00	0.030	0.19	0.01
DMDM	0.406	0.005	0.009	10000	1	0.007	2.00	0.017	0.39	0.02
UME	0.402	0.003	0.006	289	1	0.003	2.00	0.013	0.21	0.04
NIMT	0.396	0.009	0.009	2201	1	-0.003	2.00	0.017	0.20	0.02
NMC/A*STAR	0.402	0.005	0.010	10000	1	0.002	2.00	0.020	0.11	0.02
CMS/ITRI	0.397	0.004	0.003	214	1	-0.003	2.00	0.005	0.55	0.21
NMISA	0.371	0.006	0.013	10000	1	-0.029	2.00	0.025	1.13	0.01
INMETRO	0.400	0.002	0.011	10000	1	0.000	2.00	0.021	0.02	0.02

	x_w		$u(x_w)$	ν_{eff}	$N-1$		k_{ref}
Reference value	**0.399**		**0.001**	**1828**	**16**		**2.00**
C	1.76E-06						

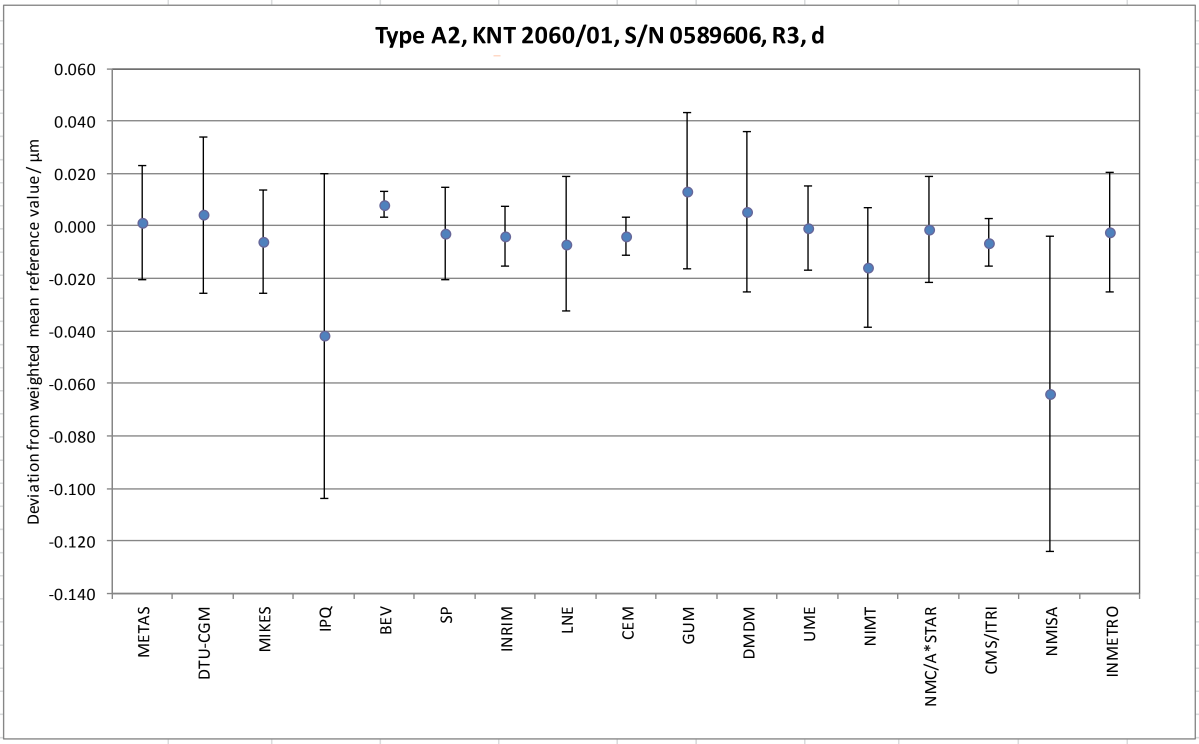
Consistency:		
u_{ext}	0.001	
R_B	0.862	**Birge ok**
Limit	1.307	



select gauge	3	Type A2, KNT 2060/01, S/N 0589606, R3, d			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	1.343	0.006	0.011	116	1	0.001	2.00	0.022	0.06	0.02
DTU-CGM	1.346	0.003	0.015	10000	1	0.004	2.00	0.030	0.14	0.01
MIKES	1.336	0.006	0.010	9	1	-0.006	2.00	0.020	0.29	0.03
IPQ	1.300	0.003	0.031	110	1	-0.042	2.00	0.062	0.67	0.00
BEV	1.350	0.003	0.003	10000	1	0.008	2.00	0.005	1.68	0.33
SP	1.339	0.003	0.009	221	1	-0.003	2.00	0.018	0.16	0.04
INRIM	1.338	0.005	0.006	81	1	-0.004	2.00	0.011	0.33	0.08
LNE	1.335	0.018	0.013	67	1	-0.007	2.00	0.026	0.26	0.02
CEM	1.338	0.003	0.004	10000	1	-0.004	2.00	0.007	0.52	0.19
GUM	1.355	0.006	0.015	17	1	0.013	2.00	0.030	0.44	0.01
DMDM	1.347	0.007	0.015	10000	1	0.005	2.00	0.031	0.17	0.01
UME	1.341	0.002	0.008	454	1	-0.001	2.00	0.016	0.05	0.05
NIMT	1.326	0.002	0.012	311811	1	-0.016	2.00	0.023	0.69	0.02
NMC/A*STAR	1.340	0.004	0.010	10000	1	-0.001	2.00	0.020	0.07	0.03
CMS/ITRI	1.335	0.002	0.005	171	1	-0.006	2.00	0.009	0.71	0.13
NMISA	1.278	0.005	0.030	10000	1	-0.064	2.00	0.060	1.07	0.00
INMETRO	1.340	0.002	0.012	10000	1	-0.002	2.00	0.023	0.10	0.02

	x_w		$u(x_w)$	ν_{eff}	$N-1$		k_{ref}
Reference value	**1.342**		**0.002**	**3074**	**16**		**2.00**
C	2.97E-06						

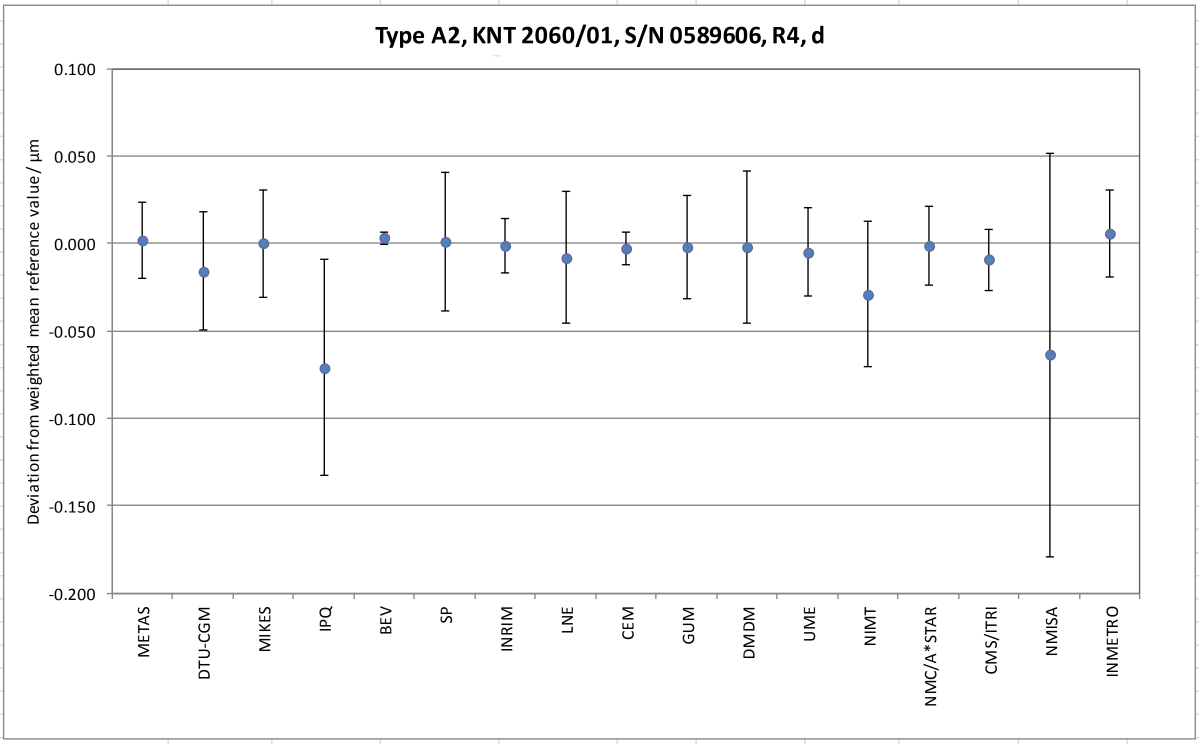
Consistency:		
u_{ext}	0.002	
R_B	1.132	Birge ok
Limit	1.307	



select gauge	4	Type A2, KNT 2060/01, S/N 0589606, R4, d			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	2.713	0.008	0.011	99	1	0.002	2.00	0.022	0.09	0.03
DTU-CGM	2.695	0.011	0.017	10000	1	-0.016	2.00	0.034	0.47	0.01
MIKES	2.711	0.007	0.016	9	1	0.000	2.00	0.031	0.00	0.01
IPQ	2.640	0.004	0.031	111	1	-0.071	2.00	0.062	1.15	0.00
BEV	2.714	0.002	0.003	10000	1	0.003	2.00	0.003	0.92	0.57
SP	2.712	0.004	0.020	545	1	0.001	2.00	0.040	0.03	0.01
INRIM	2.710	0.011	0.008	81	1	-0.001	2.00	0.016	0.06	0.06
LNE	2.703	0.020	0.019	27	1	-0.008	2.00	0.038	0.21	0.01
CEM	2.708	0.007	0.005	10000	1	-0.003	2.00	0.009	0.32	0.14
GUM	2.709	0.004	0.015	21	1	-0.002	2.00	0.030	0.07	0.02
DMDM	2.709	0.015	0.022	10000	1	-0.002	2.00	0.043	0.05	0.01
UME	2.706	0.007	0.013	330	1	-0.005	2.00	0.025	0.20	0.02
NIMT	2.682	0.009	0.021	3149	1	-0.029	2.00	0.042	0.69	0.01
NMC/A*STAR	2.710	0.011	0.012	10000	1	-0.001	2.00	0.023	0.06	0.03
CMS/ITRI	2.702	0.009	0.009	129	1	-0.009	2.00	0.018	0.53	0.04
NMISA	2.647	0.008	0.058	10000	1	-0.064	2.00	0.115	0.55	0.00
INMETRO	2.717	0.017	0.013	10000	1	0.006	2.00	0.025	0.24	0.02

	x_w		$u(x_w)$	ν_{eff}	N - 1		k_{ref}
Reference value	**2.711**		**0.002**	**7159**	**16**		**2.00**
C	3.58E-06						

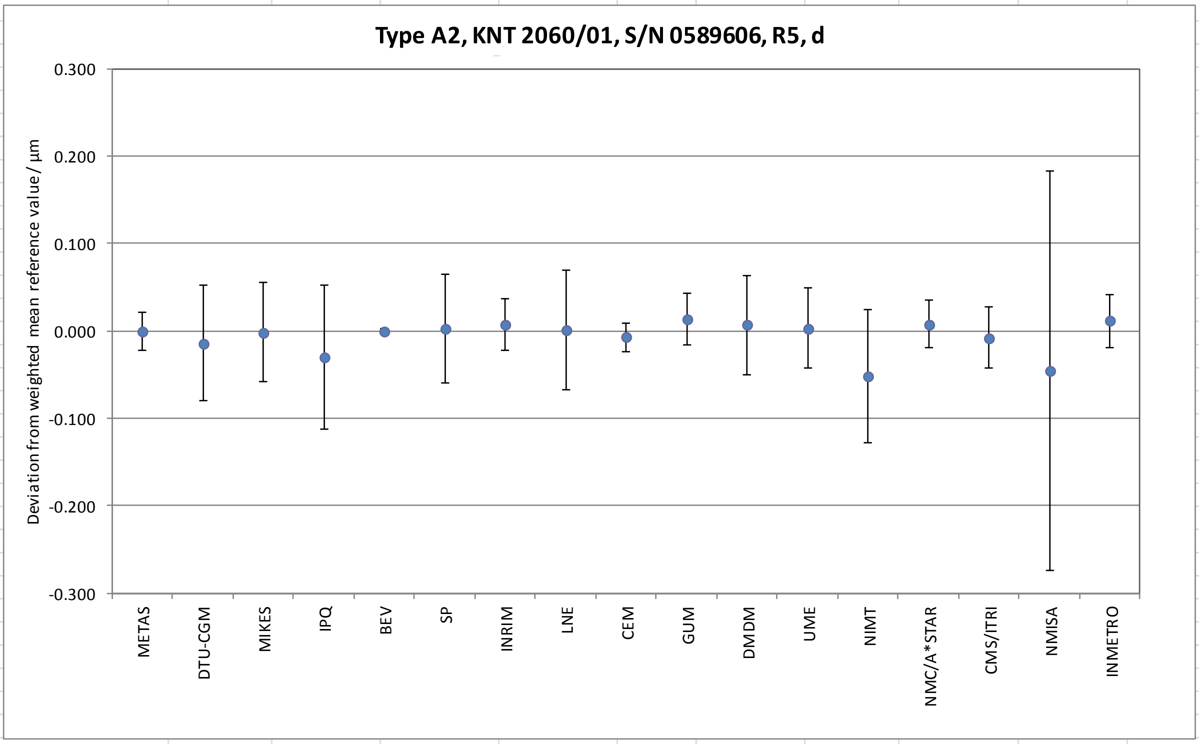
Consistency:		
u_{ext}	0.002	
R_B	0.894	Birge ok
Limit	1.307	



select gauge	5	Type A2, KNT 2060/01, S/N 0589606, R5, d			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	5.520	0.007	0.011	107	1	0.000	2.00	0.021	0.00	0.05
DTU-CGM	5.506	0.013	0.033	10000	1	-0.014	2.00	0.066	0.21	0.01
MIKES	5.519	0.009	0.029	9	1	-0.001	2.00	0.057	0.02	0.01
IPQ	5.490	0.027	0.041	41	1	-0.030	2.00	0.082	0.37	0.00
BEV	5.520	0.003	0.003	10000	1	0.000	2.00	0.003	0.01	0.68
SP	5.523	0.005	0.031	221	1	0.003	2.00	0.062	0.05	0.01
INRIM	5.528	0.009	0.015	96	1	0.008	2.00	0.030	0.27	0.03
LNE	5.521	0.021	0.034	16	1	0.001	2.00	0.068	0.01	0.01
CEM	5.513	0.007	0.009	10000	1	-0.007	2.00	0.016	0.43	0.08
GUM	5.533	0.010	0.015	30	1	0.013	2.00	0.030	0.44	0.03
DMDM	5.527	0.013	0.029	10000	1	0.007	2.00	0.057	0.12	0.01
UME	5.523	0.008	0.023	242	1	0.003	2.00	0.046	0.07	0.01
NIMT	5.468	0.009	0.038	34238	1	-0.052	2.00	0.076	0.68	0.00
NMC/A*STAR	5.527	0.016	0.014	10000	1	0.007	2.00	0.027	0.27	0.03
CMS/ITRI	5.512	0.010	0.018	109	1	-0.008	2.00	0.035	0.23	0.02
NMISA	5.474	0.009	0.114	10000	1	-0.046	2.00	0.228	0.20	0.00
INMETRO	5.531	0.008	0.016	10000	1	0.011	2.00	0.031	0.37	0.03

	x_w		$u(x_w)$	ν_{eff}	$N-1$		k_{ref}
Reference value	**5.520**		**0.002**	**8602**	**16**		**2.00**
C	6.12E-06						

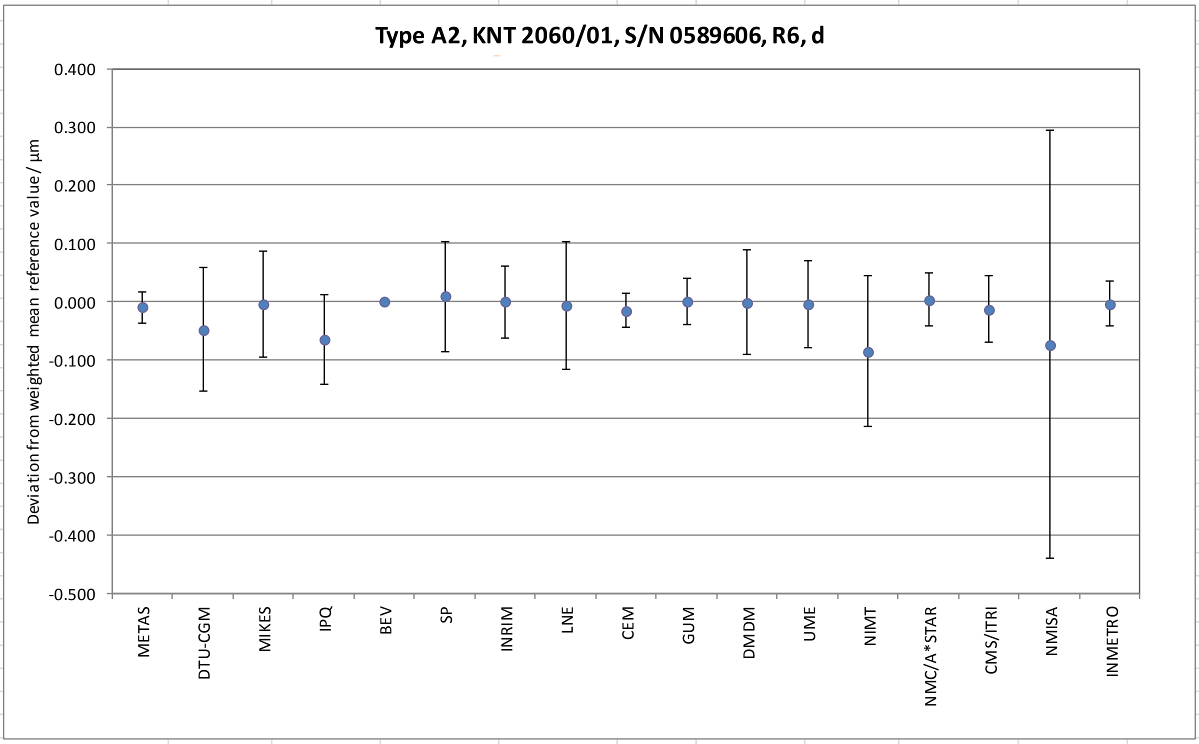
Consistency:		
u_{ext}	0.001	
R_B	0.589	**Birge ok**
Limit	1.307	



select gauge	6	Type A2, KNT 2060/01, S/N 0589606, R6, d			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	8.915	0.020	0.014	20	1	-0.010	2.00	0.028	0.35	0.03
DTU-CGM	8.877	0.020	0.053	10000	1	-0.048	2.00	0.106	0.45	0.00
MIKES	8.920	0.017	0.045	9	1	-0.005	2.00	0.090	0.05	0.00
IPQ	8.860	0.023	0.038	56	1	-0.065	2.00	0.076	0.85	0.00
BEV	8.926	0.001	0.003	10000	1	0.001	2.00	0.002	0.77	0.87
SP	8.934	0.001	0.047	159	1	0.009	2.00	0.094	0.10	0.00
INRIM	8.925	0.032	0.031	88	1	0.000	2.00	0.062	0.01	0.01
LNE	8.919	0.040	0.055	16	1	-0.006	2.00	0.110	0.05	0.00
CEM	8.910	0.026	0.015	10000	1	-0.015	2.00	0.029	0.51	0.03
GUM	8.926	0.013	0.020	43	1	0.001	2.00	0.040	0.03	0.01
DMDM	8.924	0.028	0.045	10000	1	-0.001	2.00	0.090	0.01	0.00
UME	8.920	0.021	0.037	227	1	-0.005	2.00	0.074	0.06	0.00
NIMT	8.840	0.029	0.065	2495	1	-0.085	2.00	0.130	0.65	0.00
NMC/A*STAR	8.929	0.039	0.022	11	1	0.004	2.00	0.045	0.09	0.01
CMS/ITRI	8.912	0.028	0.029	113	1	-0.013	2.00	0.057	0.22	0.01
NMISA	8.852	0.030	0.184	10000	1	-0.073	2.00	0.367	0.20	0.00
INMETRO	8.922	0.019	0.019	10000	1	-0.003	2.00	0.038	0.08	0.02

	x_w		$u(x_w)$	ν_{eff}	$N - 1$		k_{ref}
Reference value	**8.925**		**0.002**	**7553**	**16**		**2.00**
C	5.46E-06						

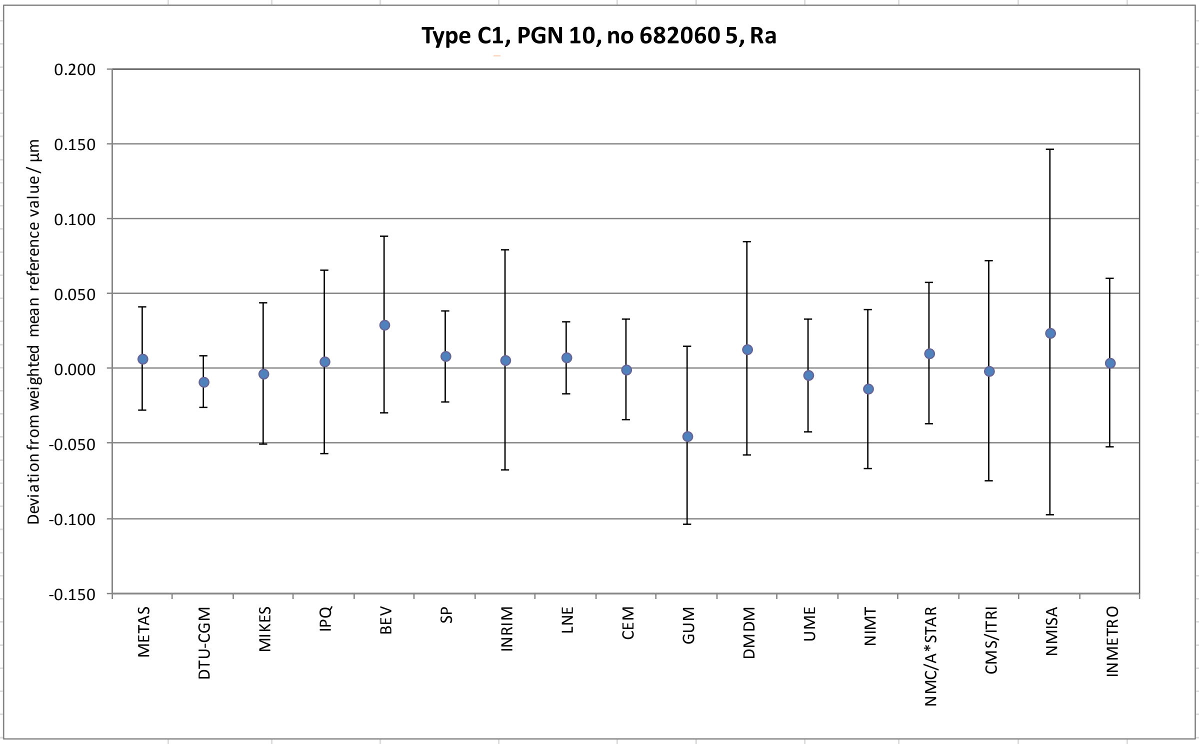
Consistency:		
u_{ext}	0.002	
R_B	0.692	**Birge ok**
Limit	1.307	



select gauge	7	Type C1, PGN 10, no 682060 5, Ra			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	2.372	0.024	0.018	182	1	0.006	2.00	0.035	0.18	0.08
DTU-CGM	2.357	0.025	0.010	10000	1	-0.009	2.00	0.017	0.50	0.25
MIKES	2.362	0.001	0.024	11	1	-0.003	2.00	0.047	0.07	0.04
IPQ	2.370	0.007	0.031	118	1	0.004	2.00	0.061	0.07	0.03
BEV	2.395	0.037	0.030	10000	1	0.029	2.00	0.059	0.50	0.03
SP	2.374	0.010	0.016	50	1	0.008	2.00	0.030	0.27	0.10
INRIM	2.371	0.034	0.037	31	1	0.005	2.00	0.073	0.07	0.02
LNE	2.373	0.033	0.013	86	1	0.007	2.00	0.024	0.31	0.15
CEM	2.365	0.032	0.018	10000	1	-0.001	2.00	0.034	0.02	0.08
GUM	2.321	0.003	0.030	16	1	-0.045	2.00	0.059	0.75	0.03
DMDM	2.379	0.026	0.036	10000	1	0.013	2.00	0.071	0.19	0.02
UME	2.361	0.030	0.020	77	1	-0.005	2.00	0.038	0.12	0.06
NIMT	2.352	0.034	0.027	573	1	-0.014	2.00	0.053	0.26	0.03
NMC/A*STAR	2.376	0.037	0.024	10000	1	0.010	2.00	0.047	0.22	0.04
CMS/ITRI	2.364	0.029	0.037	15	1	-0.002	2.00	0.073	0.02	0.02
NMISA	2.390	0.033	0.061	10000	1	0.024	2.00	0.122	0.20	0.01
INMETRO	2.369	0.024	0.029	163	1	0.004	2.00	0.056	0.07	0.03

	x_w		$u(x_w)$	ν_{eff}	$N-1$		k_{ref}
Reference value	**2.366**		**0.005**	**1282**	**16**		**2.00**
C	2.46E-05						

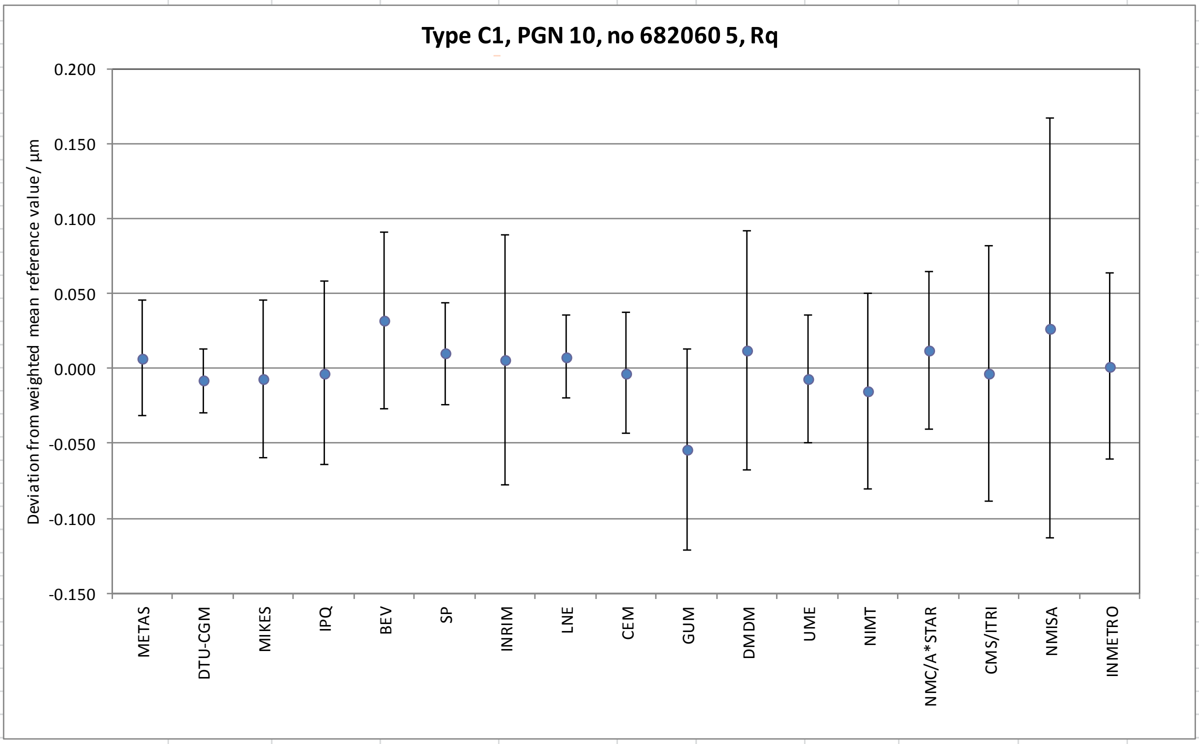
Consistency:		
u_{ext}	0.003	
R_B	0.587	Birge ok
Limit	1.307	



select gauge	8	Type C1, PGN 10, no 682060 5, Rq			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	2.660	0.028	0.020	174	1	0.007	2.00	0.038	0.18	0.08
DTU-CGM	2.645	0.030	0.012	10000	1	-0.008	2.00	0.021	0.38	0.22
MIKES	2.647	0.002	0.027	11	1	-0.007	2.00	0.053	0.13	0.04
IPQ	2.650	0.006	0.031	117	1	-0.003	2.00	0.061	0.05	0.03
BEV	2.685	0.043	0.030	10000	1	0.032	2.00	0.059	0.54	0.04
SP	2.663	0.012	0.018	46	1	0.010	2.00	0.034	0.29	0.10
INRIM	2.659	0.039	0.042	30	1	0.006	2.00	0.083	0.07	0.02
LNE	2.661	0.038	0.015	90	1	0.008	2.00	0.028	0.29	0.14
CEM	2.650	0.038	0.021	10000	1	-0.003	2.00	0.040	0.08	0.07
GUM	2.599	0.005	0.034	14	1	-0.054	2.00	0.067	0.81	0.03
DMDM	2.665	0.032	0.040	10000	1	0.012	2.00	0.080	0.15	0.02
UME	2.646	0.036	0.022	77	1	-0.007	2.00	0.043	0.17	0.07
NIMT	2.638	0.040	0.033	684	1	-0.015	2.00	0.065	0.23	0.03
NMC/A*STAR	2.665	0.043	0.027	10000	1	0.012	2.00	0.053	0.23	0.04
CMS/ITRI	2.650	0.034	0.043	15	1	-0.003	2.00	0.085	0.04	0.02
NMISA	2.680	0.040	0.070	10000	1	0.027	2.00	0.140	0.19	0.01
INMETRO	2.655	0.028	0.032	100	1	0.001	2.00	0.062	0.02	0.03

	x_w		$u(x_w)$	ν_{eff}	$N - 1$		k_{ref}
Reference value	**2.653**		**0.006**	**1194**	**16**		**2.00**
C	3.23E-05						

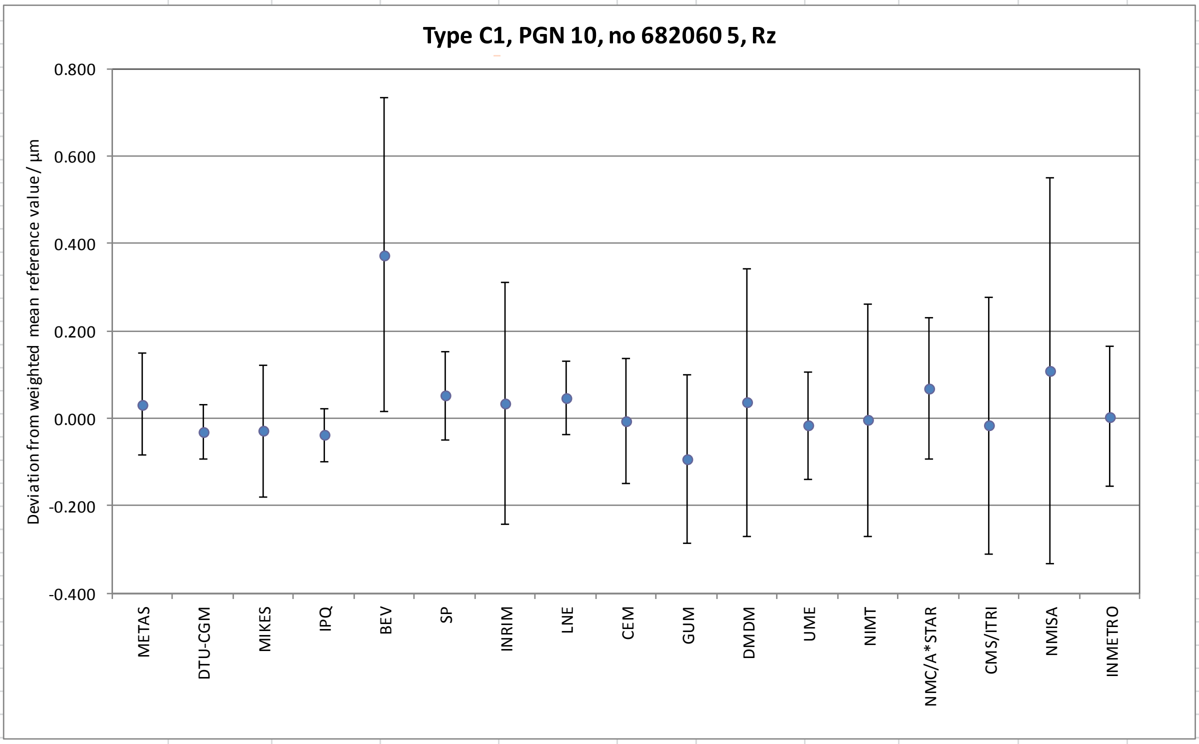
Consistency:		
u_{ext}	0.003	
R_B	0.596	**Birge ok**
Limit	1.307	



select gauge	9	Type C1, PGN 10, no 682060 5, Rz			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	$(x_i - x_w)$/µm	k	$U(x_i - x_{ref})$/µm	E_n	w_i
METAS	7.700	0.100	0.060	164	1	0.032	2.00	0.116	0.28	0.07
DTU-CGM	7.637	0.099	0.035	10000	1	-0.031	2.00	0.063	0.49	0.20
MIKES	7.639	0.017	0.077	11	1	-0.029	2.00	0.152	0.19	0.04
IPQ	7.630	0.015	0.034	164	1	-0.038	2.00	0.060	0.63	0.21
BEV	8.042	0.165	0.180	10000	1	0.374	2.00	0.359	1.04	0.01
SP	7.720	0.039	0.053	35	1	0.052	2.00	0.101	0.52	0.09
INRIM	7.703	0.134	0.139	24	1	0.035	2.00	0.276	0.13	0.01
LNE	7.715	0.127	0.045	23	1	0.047	2.00	0.084	0.56	0.12
CEM	7.661	0.132	0.073	10000	1	-0.007	2.00	0.143	0.05	0.05
GUM	7.575	0.028	0.097	10	1	-0.093	2.00	0.191	0.48	0.03
DMDM	7.704	0.109	0.154	10000	1	0.036	2.00	0.307	0.12	0.01
UME	7.651	0.133	0.063	77	1	-0.017	2.00	0.123	0.14	0.06
NIMT	7.664	0.135	0.134	1517	1	-0.004	2.00	0.266	0.01	0.01
NMC/A*STAR	7.737	0.152	0.082	10000	1	0.069	2.00	0.161	0.43	0.04
CMS/ITRI	7.651	0.120	0.147	13	1	-0.017	2.00	0.292	0.06	0.01
NMISA	7.777	0.153	0.221	10000	1	0.109	2.00	0.441	0.25	0.01
INMETRO	7.672	0.097	0.082	40	1	0.004	2.00	0.160	0.03	0.04

	x_w		$u(x_w)$	ν_{eff}	$N - 1$		k_{ref}
Reference value	**7.668**		**0.016**	**671**	**16**		**2.00**
C	2.46E-04						

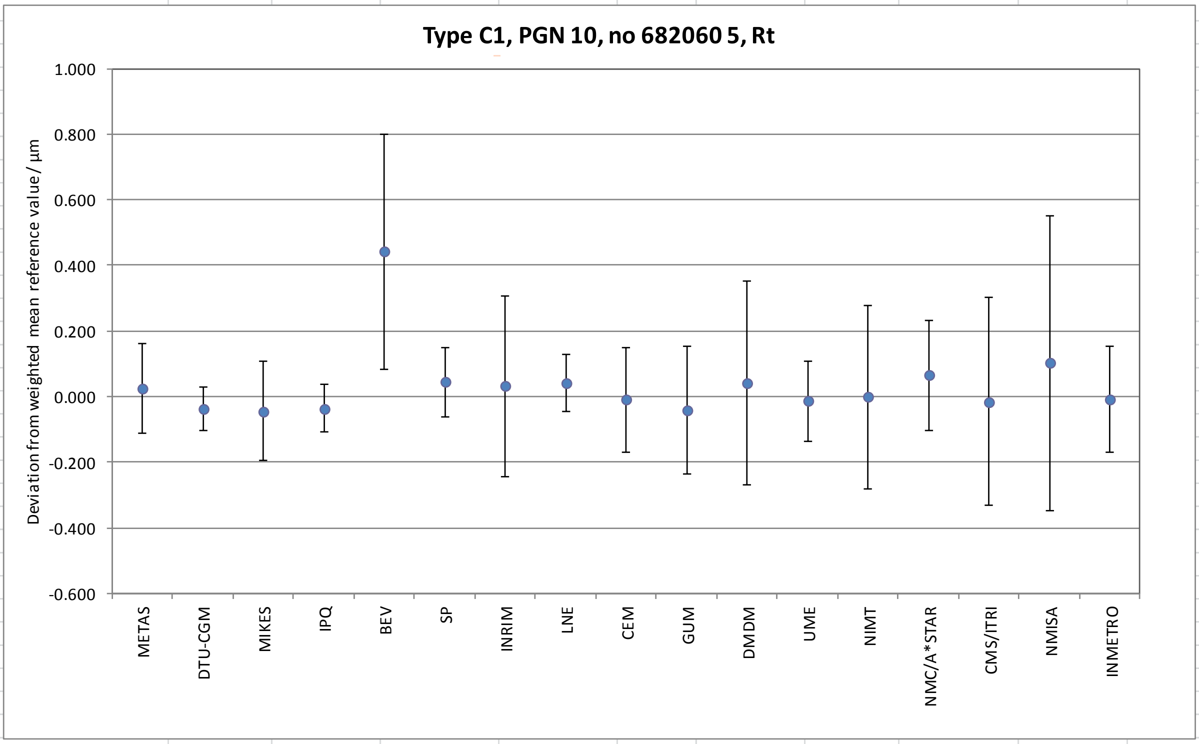
Consistency:		
u_{ext}	0.013	
R_B	0.826	Birge ok
Limit	1.307	



select gauge	10	Type C1, PGN 10, no 682060 5, Rt			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	$(x_i$-$x_w)$/µm	k	$U(x_i$-$x_{ref})$/µm	E_n	w_i
METAS	7.760	0.110	0.070	131	1	0.024	2.00	0.136	0.18	0.06
DTU-CGM	7.698	0.109	0.038	10000	1	-0.038	2.00	0.068	0.55	0.20
MIKES	7.691	0.024	0.078	11	1	-0.045	2.00	0.152	0.29	0.05
IPQ	7.700	0.026	0.040	284	1	-0.036	2.00	0.072	0.49	0.18
BEV	8.177	0.190	0.180	10000	1	0.441	2.00	0.358	1.23	0.01
SP	7.780	0.040	0.055	32	1	0.044	2.00	0.105	0.42	0.09
INRIM	7.767	0.142	0.139	24	1	0.031	2.00	0.276	0.11	0.01
LNE	7.778	0.134	0.047	23	1	0.042	2.00	0.088	0.48	0.13
CEM	7.726	0.148	0.082	10000	1	-0.010	2.00	0.159	0.06	0.04
GUM	7.694	0.028	0.098	10	1	-0.042	2.00	0.193	0.22	0.03
DMDM	7.777	0.122	0.156	10000	1	0.041	2.00	0.310	0.13	0.01
UME	7.721	0.140	0.064	77	1	-0.015	2.00	0.124	0.12	0.07
NIMT	7.735	0.145	0.141	1404	1	-0.001	2.00	0.280	0.00	0.01
NMC/A*STAR	7.800	0.165	0.085	10000	1	0.064	2.00	0.167	0.39	0.04
CMS/ITRI	7.720	0.131	0.159	13	1	-0.016	2.00	0.316	0.05	0.01
NMISA	7.838	0.157	0.225	10000	1	0.102	2.00	0.449	0.23	0.01
INMETRO	7.727	0.110	0.082	17	1	-0.009	2.00	0.160	0.05	0.04

	x_w		$u(x_w)$	ν_{eff}	N - 1		k_{ref}
Reference value	**7.736**		**0.017**	**611**	**16**		**2.00**
C	2.87E-04						

Consistency:		
u_{ext}	0.014	
R_B	0.824	Birge ok
Limit	1.307	



select gauge 11 Type C1, PGN 10, no 682060 5, RSm

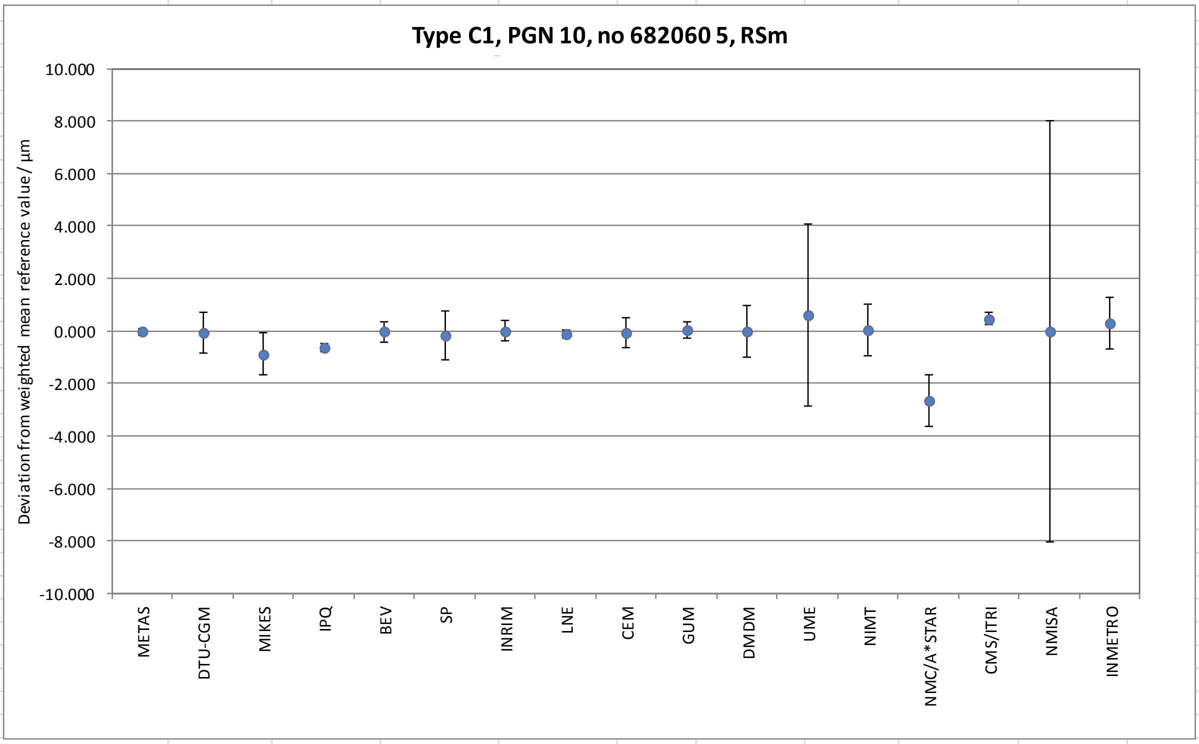
use 1 or 0 to in- or exclude

choose: k=2

Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	199.930	0.160	0.075	20	1	-0.035	2.00	0.120	0.29	0.36
DTU-CGM	199.900	0.100	0.388	10000	1	-0.065	2.00	0.771	0.08	0.01
MIKES	199.079	0.267	0.400	11	1	-0.886	2.00	0.795	1.11	0.01
IPQ	199.330	0.071	0.077	606	0	-0.635	2.00	0.178	3.56	0.00
BEV	199.940	0.080	0.200	10000	1	-0.025	2.00	0.390	0.06	0.05
SP	199.800	0.030	0.466	11	1	-0.165	2.00	0.928	0.18	0.01
INRIM	199.960	0.070	0.199	115	1	-0.005	2.00	0.388	0.01	0.05
LNE	199.835	0.195	0.090	42	1	-0.130	2.00	0.156	0.83	0.25
CEM	199.900	0.251	0.300	10000	1	-0.065	2.00	0.593	0.11	0.02
GUM	200.000	0.024	0.150	100	1	0.035	2.00	0.286	0.12	0.09
DMDM	199.955	0.071	0.500	10000	1	-0.010	2.00	0.996	0.01	0.01
UME	200.576	0.088	1.735	215	1	0.611	2.00	3.469	0.18	0.00
NIMT	200.000	0.000	0.495	1000	1	0.035	2.00	0.986	0.04	0.01
NMC/A*STAR	197.329	0.792	0.492	10000	0	-2.636	2.00	0.988	2.67	0.00
CMS/ITRI	200.428	0.481	0.130	16	1	0.463	2.00	0.244	1.90	0.12
NMISA	199.948	0.040	4.003	10000	1	-0.017	2.00	8.006	0.00	0.00
INMETRO	200.273	0.055	0.500	10000	1	0.308	2.00	0.996	0.31	0.01

	x_w	$u(x_w)$	ν_{eff}	$N-1$	k_{ref}
Reference value	**199.965**	**0.045**	**112**	**14**	**2.00**
C	2.02E-03				

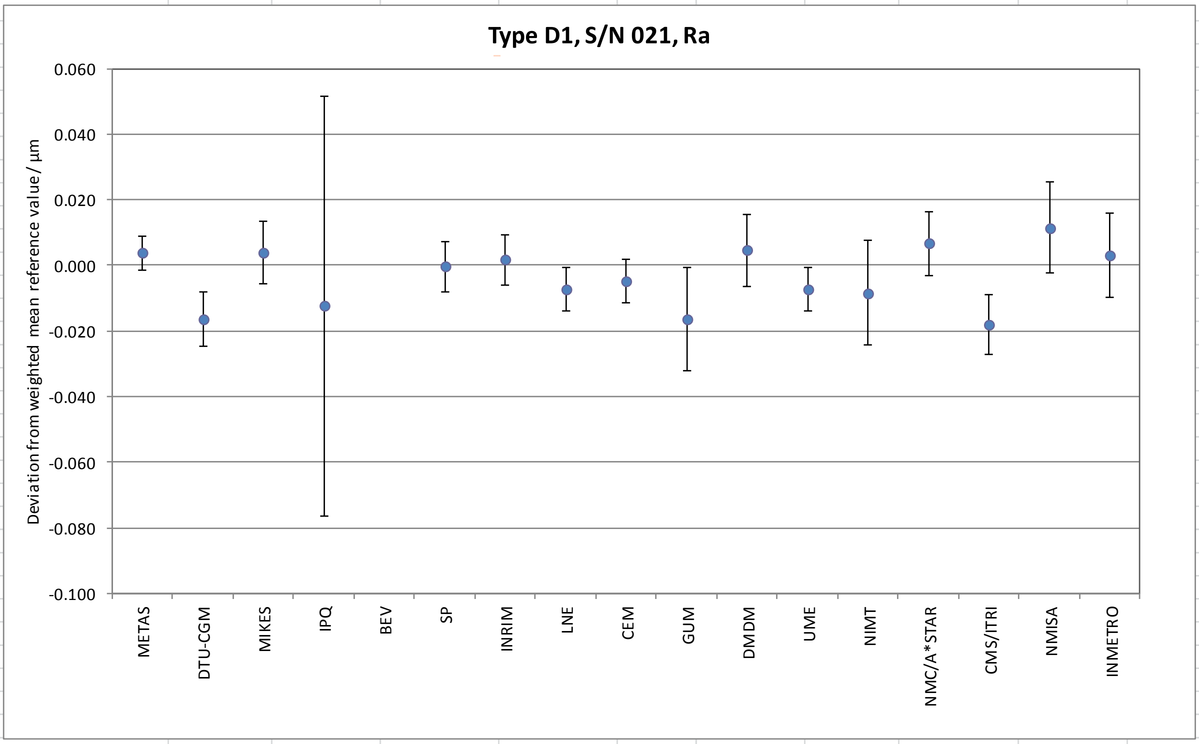
Consistency:		
u_{ext}	0.055	
R_B	1.215	Birge ok
Limit	1.325	



select gauge	12	Type D1, S/N 021, Ra			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	0.126	0.002	0.003	229	1	0.004	2.00	0.005	0.72	0.20
DTU-CGM	0.106	0.002	0.004	10000	0	-0.016	2.00	0.008	1.95	0.00
MIKES	0.126	0.001	0.005	11	1	0.004	2.00	0.010	0.41	0.07
IPQ	0.110	0.004	0.032	131	1	-0.012	2.00	0.064	0.19	0.00
BEV	0.000	0.000	0.000	#NV	0	#NV	#NV	#NV	#NV	0.00
SP	0.122	0.002	0.004	128	1	0.000	2.00	0.008	0.05	0.11
INRIM	0.124	0.002	0.004	164	1	0.002	2.00	0.008	0.22	0.11
LNE	0.115	0.002	0.003	36	0	-0.007	2.00	0.007	1.13	0.00
CEM	0.118	0.002	0.004	10000	1	-0.005	2.00	0.007	0.75	0.14
GUM	0.106	0.002	0.008	42	1	-0.016	2.00	0.016	1.04	0.03
DMDM	0.127	0.001	0.006	10000	1	0.005	2.00	0.011	0.43	0.05
UME	0.115	0.001	0.004	173	1	-0.007	2.00	0.007	1.13	0.14
NIMT	0.114	0.002	0.008	82689	1	-0.008	2.00	0.016	0.53	0.03
NMC/A*STAR	0.129	0.001	0.005	10000	1	0.007	2.00	0.010	0.69	0.07
CMS/ITRI	0.104	0.003	0.004	24	0	-0.018	2.00	0.009	1.97	0.00
NMISA	0.134	0.002	0.007	10000	1	0.011	2.00	0.014	0.82	0.03
INMETRO	0.125	0.002	0.007	10000	1	0.003	2.00	0.013	0.24	0.04

	x_w	$u(x_w)$	ν_{eff}	$N-1$	k_{ref}
Reference value	0.122	0.001	1153	12	2.00
C	1.68E-06				

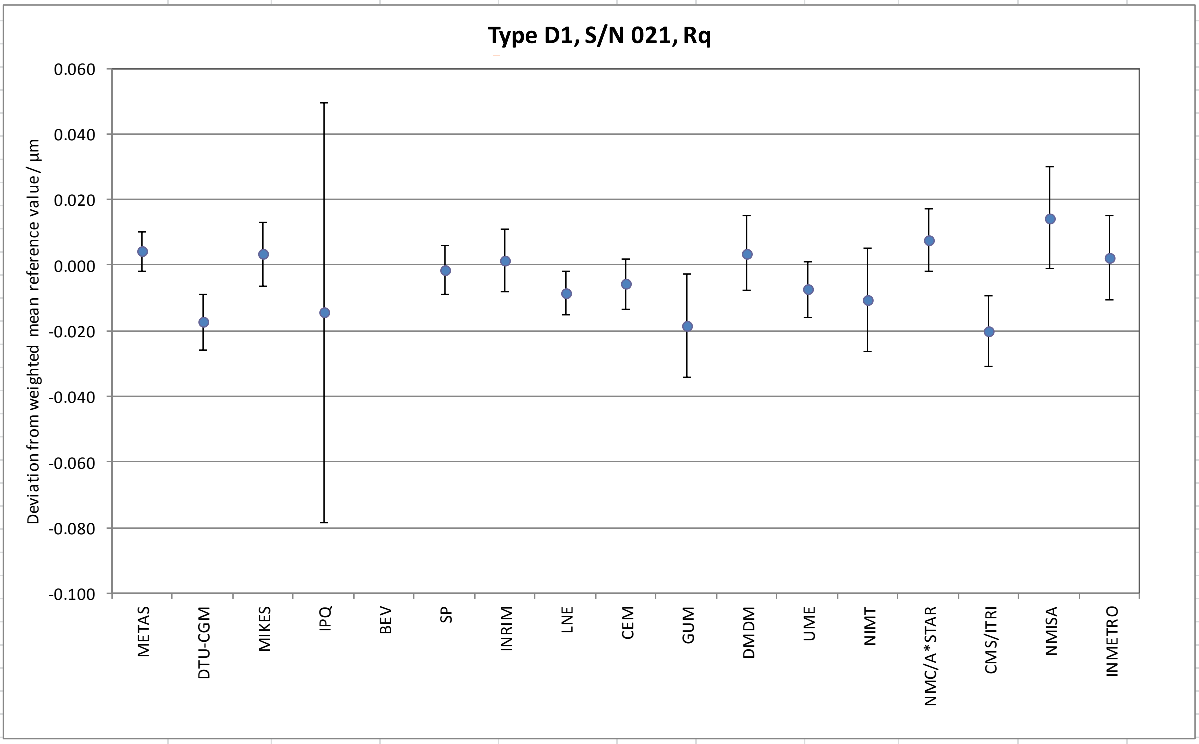
Consistency:		
u_{ext}	0.002	
R_B	1.275	Birge ok
Limit	1.348	



select gauge	13	Type D1, S/N 021, Rq			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	0.159	0.003	0.003	228	1	0.004	2.00	0.006	0.70	0.19
DTU-CGM	0.137	0.003	0.004	10000	0	-0.017	2.00	0.009	2.05	0.00
MIKES	0.158	0.001	0.005	11	1	0.003	2.00	0.010	0.34	0.08
IPQ	0.140	0.005	0.032	132	1	-0.014	2.00	0.064	0.23	0.00
BEV	0.000	0.000	0.000	#NV	0	#NV	#NV	#NV	#NV	0.00
SP	0.153	0.002	0.004	111	1	-0.001	2.00	0.007	0.19	0.13
INRIM	0.156	0.003	0.005	73	1	0.002	2.00	0.010	0.16	0.08
LNE	0.146	0.002	0.003	36	0	-0.008	2.00	0.007	1.27	0.00
CEM	0.149	0.002	0.004	10000	1	-0.006	2.00	0.008	0.76	0.12
GUM	0.136	0.003	0.008	45	1	-0.018	2.00	0.016	1.17	0.03
DMDM	0.158	0.001	0.006	10000	1	0.004	2.00	0.011	0.31	0.06
UME	0.147	0.002	0.005	173	1	-0.007	2.00	0.009	0.87	0.10
NIMT	0.144	0.003	0.008	144072	1	-0.010	2.00	0.016	0.66	0.03
NMC/A*STAR	0.162	0.002	0.005	10000	1	0.008	2.00	0.010	0.79	0.08
CMS/ITRI	0.134	0.004	0.005	19	0	-0.020	2.00	0.011	1.87	0.00
NMISA	0.169	0.003	0.008	10000	1	0.014	2.00	0.015	0.93	0.03
INMETRO	0.157	0.003	0.007	10000	1	0.002	2.00	0.013	0.18	0.05

	x_w		$u(x_w)$	ν_{eff}	N - 1		k_{ref}
Reference value	**0.154**		**0.001**	**936**	**12**		**2.00**
C	2.07E-06						

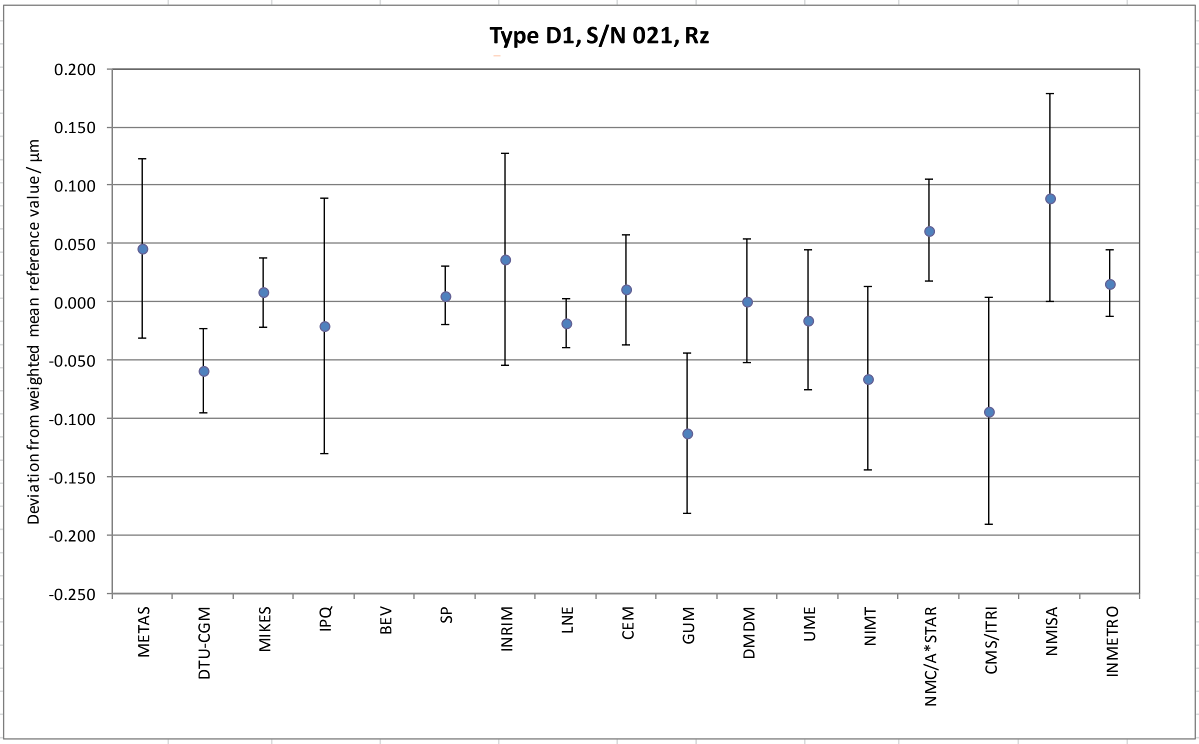
Consistency:		
u_{ext}	0.002	
R_B	1.302	**Birge ok**
Limit	1.348	



select gauge	14	Type D1, S/N 021, Rz			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	$(x_i - x_w)$/µm	k	$U(x_i - x_{ref})$/µm	E_n	w_i
METAS	1.056	0.050	0.039	162	1	0.045	2.00	0.077	0.59	0.02
DTU-CGM	0.952	0.049	0.017	10000	0	-0.059	2.00	0.036	1.62	0.00
MIKES	1.019	0.031	0.016	11	1	0.008	2.00	0.030	0.27	0.14
IPQ	0.990	0.045	0.055	128	1	-0.021	2.00	0.109	0.19	0.01
BEV	0.000	0.000	0.000	#NV	0	#NV	#NV	#NV	#NV	0.00
SP	1.016	0.013	0.014	16	1	0.005	2.00	0.025	0.21	0.19
INRIM	1.047	0.046	0.046	14	1	0.036	2.00	0.091	0.40	0.02
LNE	0.992	0.020	0.012	67	1	-0.019	2.00	0.021	0.90	0.26
CEM	1.021	0.045	0.025	10000	1	0.010	2.00	0.047	0.22	0.06
GUM	0.898	0.026	0.034	87	0	-0.113	2.00	0.069	1.63	0.00
DMDM	1.011	0.022	0.027	10000	1	0.000	2.00	0.053	0.01	0.05
UME	0.995	0.043	0.031	173	1	-0.016	2.00	0.060	0.26	0.04
NIMT	0.945	0.033	0.040	1002	1	-0.066	2.00	0.079	0.83	0.02
NMC/A*STAR	1.072	0.048	0.021	10000	0	0.061	2.00	0.044	1.40	0.00
CMS/ITRI	0.917	0.041	0.049	13	1	-0.094	2.00	0.097	0.96	0.02
NMISA	1.100	0.037	0.045	10000	1	0.089	2.00	0.089	1.00	0.02
INMETRO	1.027	0.035	0.016	10000	1	0.016	2.00	0.029	0.56	0.15

	x_w	$u(x_w)$	ν_{eff}	$N - 1$	k_{ref}
Reference value	**1.011**	**0.006**	**197**	**12**	**2.00**
C	3.68E-05				

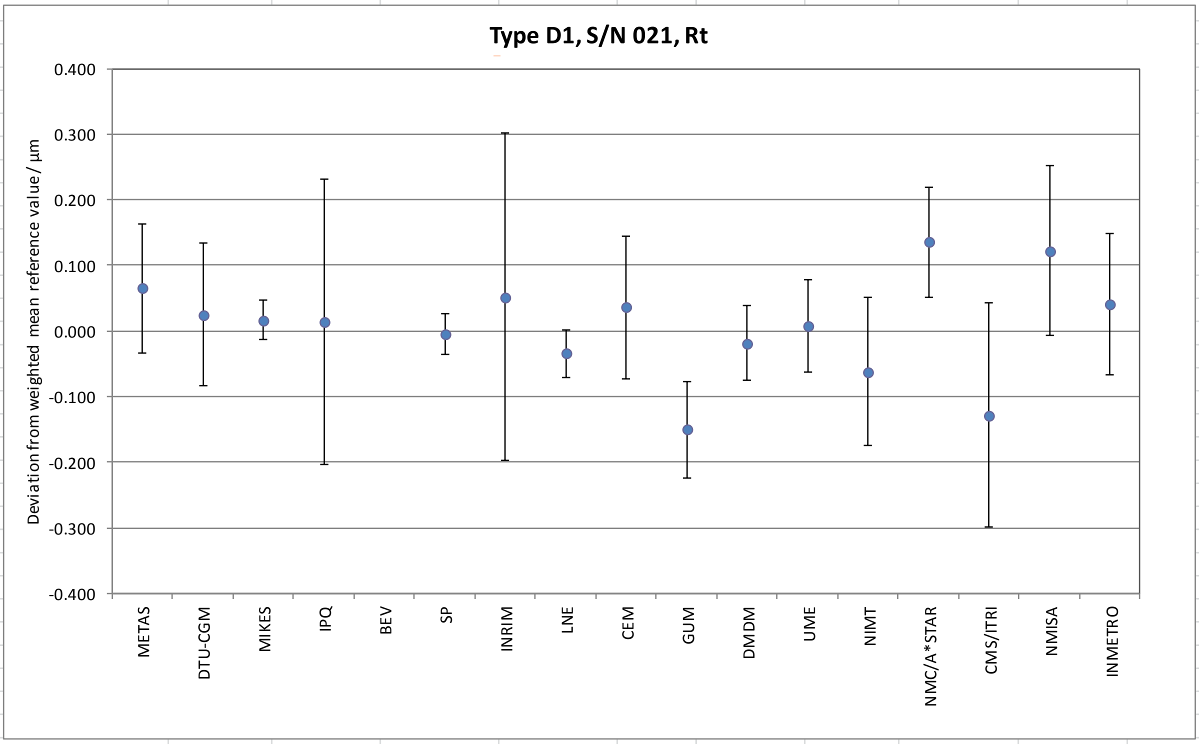
Consistency:		
u_{ext}	0.007	
R_B	1.180	**Birge ok**
Limit	1.348	



select gauge	15	Type D1, S/N 021, Rt			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	1.220	0.100	0.050	73	1	0.065	2.00	0.098	0.66	0.03
DTU-CGM	1.180	0.185	0.055	10000	1	0.025	2.00	0.109	0.23	0.03
MIKES	1.172	0.092	0.017	11	1	0.017	2.00	0.029	0.57	0.26
IPQ	1.170	0.104	0.109	77	1	0.015	2.00	0.217	0.07	0.01
BEV	0.000	0.000	0.000	#NV	0	#NV	#NV	#NV	#NV	0.00
SP	1.151	0.017	0.018	15	1	-0.004	2.00	0.031	0.14	0.24
INRIM	1.207	0.123	0.125	12	1	0.052	2.00	0.249	0.21	0.00
LNE	1.121	0.035	0.020	62	1	-0.034	2.00	0.036	0.95	0.19
CEM	1.191	0.099	0.055	10000	1	0.036	2.00	0.109	0.33	0.03
GUM	1.005	0.044	0.036	100	0	-0.150	2.00	0.074	2.03	0.00
DMDM	1.137	0.029	0.030	10000	1	-0.018	2.00	0.058	0.32	0.08
UME	1.163	0.150	0.036	173	1	0.008	2.00	0.070	0.11	0.06
NIMT	1.093	0.063	0.057	656	1	-0.062	2.00	0.113	0.55	0.02
NMC/A*STAR	1.291	0.130	0.041	10000	0	0.136	2.00	0.084	1.62	0.00
CMS/ITRI	1.027	0.073	0.086	11	1	-0.128	2.00	0.171	0.75	0.01
NMISA	1.278	0.059	0.066	10000	1	0.122	2.00	0.130	0.94	0.02
INMETRO	1.196	0.086	0.055	19	1	0.040	2.00	0.108	0.38	0.03

	x_w		$u(x_w)$	ν_{eff}	$N-1$		k_{ref}
Reference value	**1.155**		**0.009**	**95**	**13**		**2.00**
C	7.63E-05						

Consistency:		
u_{ext}	0.009	
R_B	1.050	Birge ok
Limit	1.336	



select gauge 16 **Type D1, KNT 2070/03, S/N 0986, Ra**

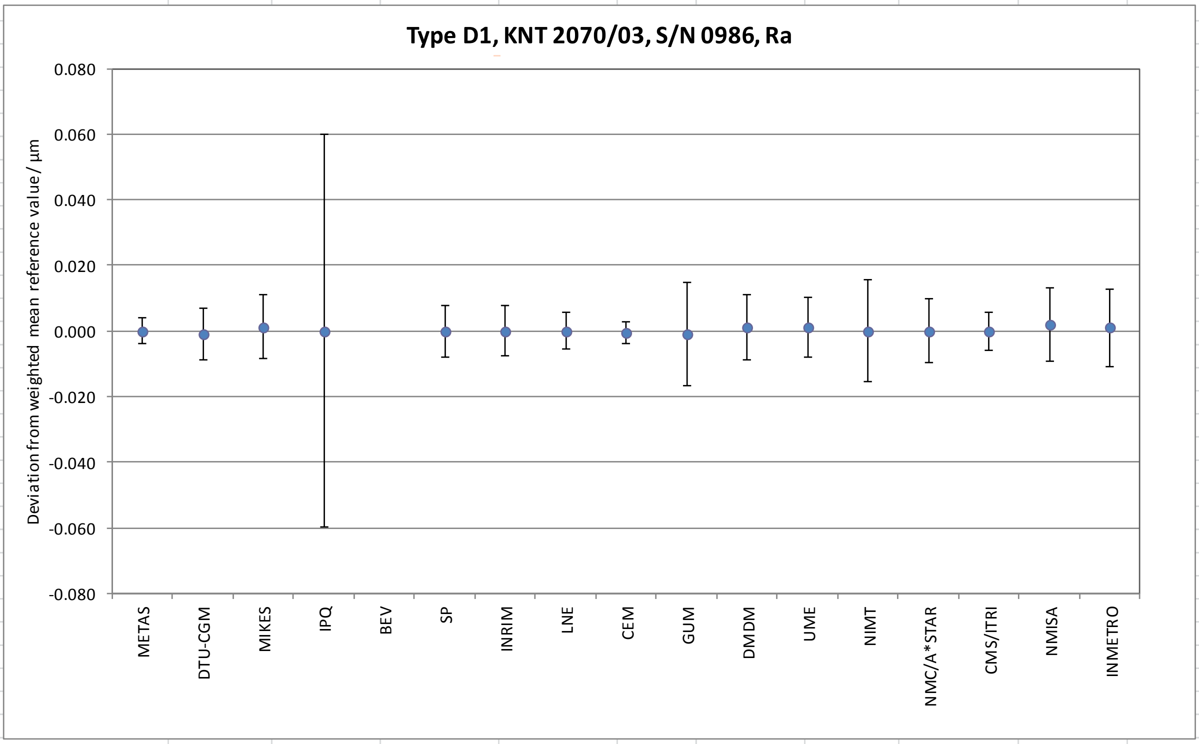
use 1 or 0 to in- or exclude

choose: *k=2*

Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	0.060	0.001	0.002	147	1	0.000	2.00	0.004	0.01	0.18
DTU-CGM	0.059	0.002	0.004	10000	1	-0.001	2.00	0.008	0.12	0.05
MIKES	0.061	0.001	0.005	11	1	0.001	2.00	0.010	0.13	0.04
IPQ	0.060	0.001	0.030	108	1	0.000	2.00	0.060	0.00	0.00
BEV	0.000	0.000	0.000	#NV	0	#NV	#NV	#NV	#NV	0.00
SP	0.060	0.001	0.004	124	1	0.000	2.00	0.008	0.01	0.05
INRIM	0.060	0.002	0.004	145	1	0.000	2.00	0.008	0.00	0.05
LNE	0.060	0.002	0.003	31	1	0.000	2.00	0.006	0.01	0.10
CEM	0.059	0.001	0.002	10000	1	-0.001	2.00	0.003	0.17	0.23
GUM	0.059	0.001	0.008	38	1	-0.001	2.00	0.016	0.06	0.01
DMDM	0.061	0.002	0.005	10000	1	0.001	2.00	0.010	0.10	0.03
UME	0.061	0.002	0.005	137	1	0.001	2.00	0.009	0.11	0.04
NIMT	0.060	0.001	0.008	1415523	1	0.000	2.00	0.015	0.00	0.01
NMC/A*STAR	0.060	0.001	0.005	10000	1	0.000	2.00	0.010	0.00	0.04
CMS/ITRI	0.060	0.001	0.003	86	1	0.000	2.00	0.006	0.01	0.10
NMISA	0.062	0.002	0.006	10000	1	0.002	2.00	0.011	0.18	0.03
INMETRO	0.061	0.002	0.006	10000	1	0.001	2.00	0.012	0.08	0.02

	x_w	$u(x_w)$	ν_{eff}	$N - 1$	k_{ref}
Reference value	**0.060**	**0.001**	**1211**	**15**	**2.00**
C	8.80E-07				

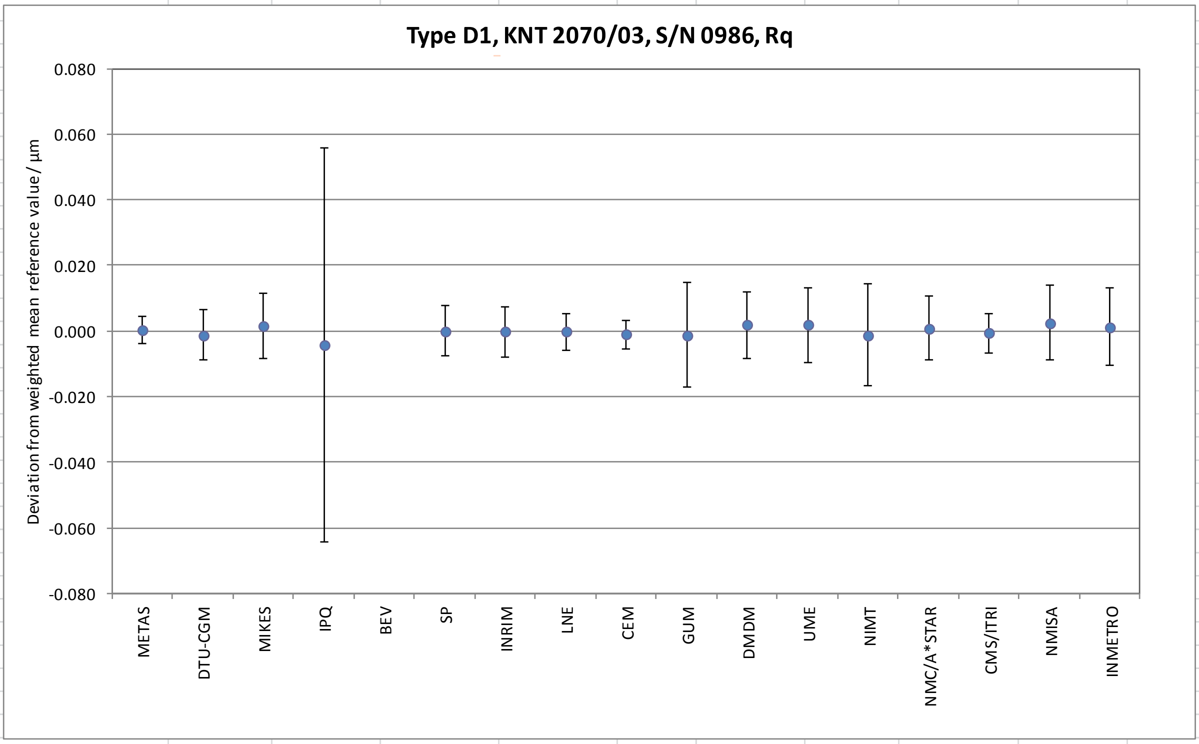
Consistency:		
u_{ext}	0.000	
R_B	0.174	**Birge ok**
Limit	1.315	



select gauge	17	Type D1, KNT 2070/03, S/N 0986, Rq			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	0.075	0.001	0.002	168	1	0.000	2.00	0.004	0.09	0.19
DTU-CGM	0.073	0.003	0.004	10000	1	-0.001	2.00	0.008	0.16	0.06
MIKES	0.076	0.001	0.005	11	1	0.002	2.00	0.010	0.16	0.04
IPQ	0.070	0.001	0.030	108	1	-0.004	2.00	0.060	0.07	0.00
BEV	0.000	0.000	0.000	#NV	0	#NV	#NV	#NV	#NV	0.00
SP	0.074	0.001	0.004	126	1	0.000	2.00	0.008	0.01	0.06
INRIM	0.074	0.002	0.004	149	1	0.000	2.00	0.008	0.03	0.06
LNE	0.074	0.002	0.003	31	1	0.000	2.00	0.006	0.04	0.11
CEM	0.073	0.001	0.002	10000	1	-0.001	2.00	0.004	0.23	0.17
GUM	0.073	0.001	0.008	38	1	-0.001	2.00	0.016	0.08	0.02
DMDM	0.076	0.002	0.005	10000	1	0.002	2.00	0.010	0.17	0.04
UME	0.076	0.002	0.006	137	1	0.002	2.00	0.011	0.16	0.03
NIMT	0.073	0.002	0.008	1046899	1	-0.001	2.00	0.016	0.08	0.02
NMC/A*STAR	0.075	0.001	0.005	10000	1	0.001	2.00	0.010	0.08	0.04
CMS/ITRI	0.074	0.002	0.003	62	1	-0.001	2.00	0.006	0.10	0.10
NMISA	0.077	0.002	0.006	10000	1	0.002	2.00	0.011	0.21	0.03
INMETRO	0.076	0.002	0.006	10000	1	0.001	2.00	0.012	0.11	0.03

	x_w		$u(x_w)$	ν_{eff}	$N-1$		k_{ref}
Reference value	**0.074**		**0.001**	**1018**	**15**		**2.00**
C	1.00E-06						

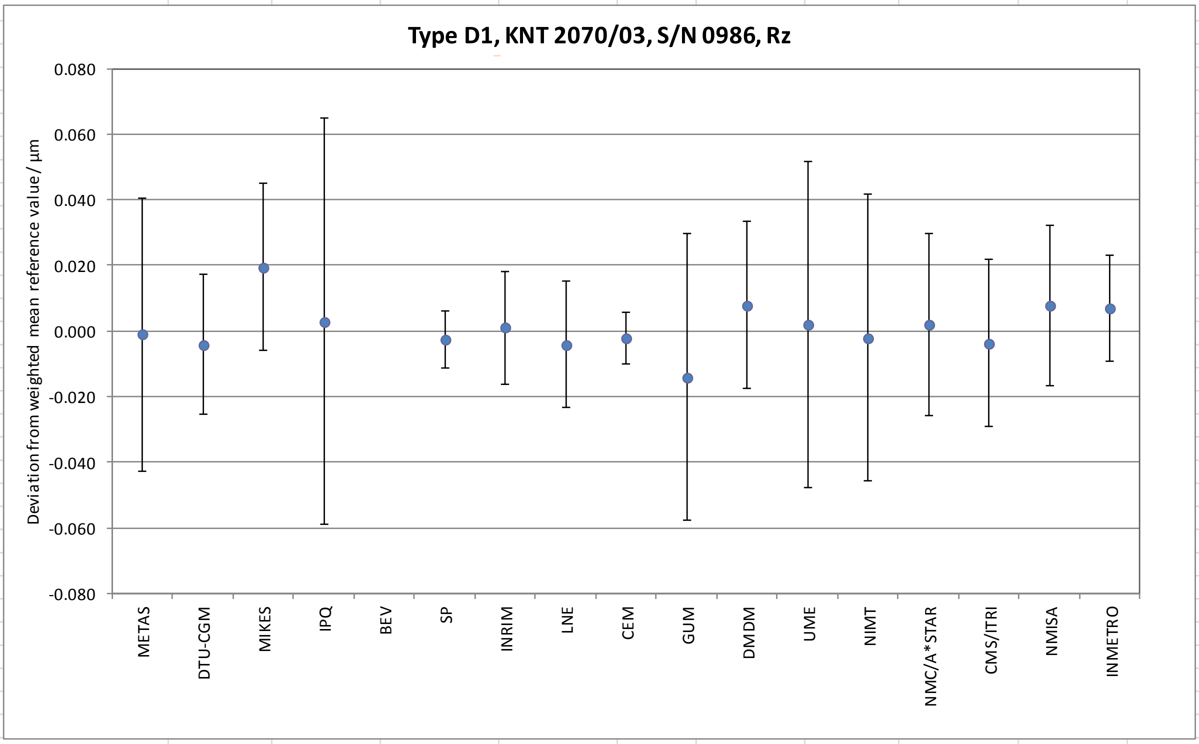
Consistency:		
u_{ext}	0.000	
R_B	0.255	**Birge ok**
Limit	1.315	



select gauge	18	Type D1, KNT 2070/03, S/N 0986, Rz			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	0.326	0.003	0.021	157	1	-0.001	2.00	0.042	0.03	0.01
DTU-CGM	0.323	0.013	0.011	10000	1	-0.004	2.00	0.021	0.19	0.05
MIKES	0.347	0.005	0.013	11	1	0.020	2.00	0.026	0.76	0.04
IPQ	0.330	0.008	0.031	122	1	0.003	2.00	0.062	0.05	0.01
BEV	0.000	0.000	0.000	#NV	0	#NV	#NV	#NV	#NV	0.00
SP	0.324	0.003	0.005	97	1	-0.003	2.00	0.009	0.31	0.24
INRIM	0.328	0.009	0.009	25	1	0.001	2.00	0.017	0.05	0.07
LNE	0.323	0.011	0.010	59	1	-0.004	2.00	0.019	0.21	0.06
CEM	0.325	0.007	0.005	10000	1	-0.002	2.00	0.008	0.26	0.27
GUM	0.313	0.004	0.022	16	1	-0.014	2.00	0.044	0.32	0.01
DMDM	0.335	0.010	0.013	10000	1	0.008	2.00	0.026	0.31	0.04
UME	0.329	0.010	0.025	137	1	0.002	2.00	0.050	0.04	0.01
NIMT	0.325	0.012	0.022	19484	1	-0.002	2.00	0.044	0.05	0.01
NMC/A*STAR	0.329	0.011	0.014	10000	1	0.002	2.00	0.028	0.07	0.03
CMS/ITRI	0.323	0.007	0.013	66	1	-0.004	2.00	0.026	0.15	0.04
NMISA	0.335	0.006	0.012	10000	1	0.008	2.00	0.024	0.32	0.04
INMETRO	0.334	0.018	0.009	10000	1	0.007	2.00	0.016	0.43	0.08

	x_w	$u(x_w)$	ν_{eff}	$N - 1$	k_{ref}
Reference value	**0.327**	**0.002**	**1000**	**15**	**2.00**
C	5.92E-06				

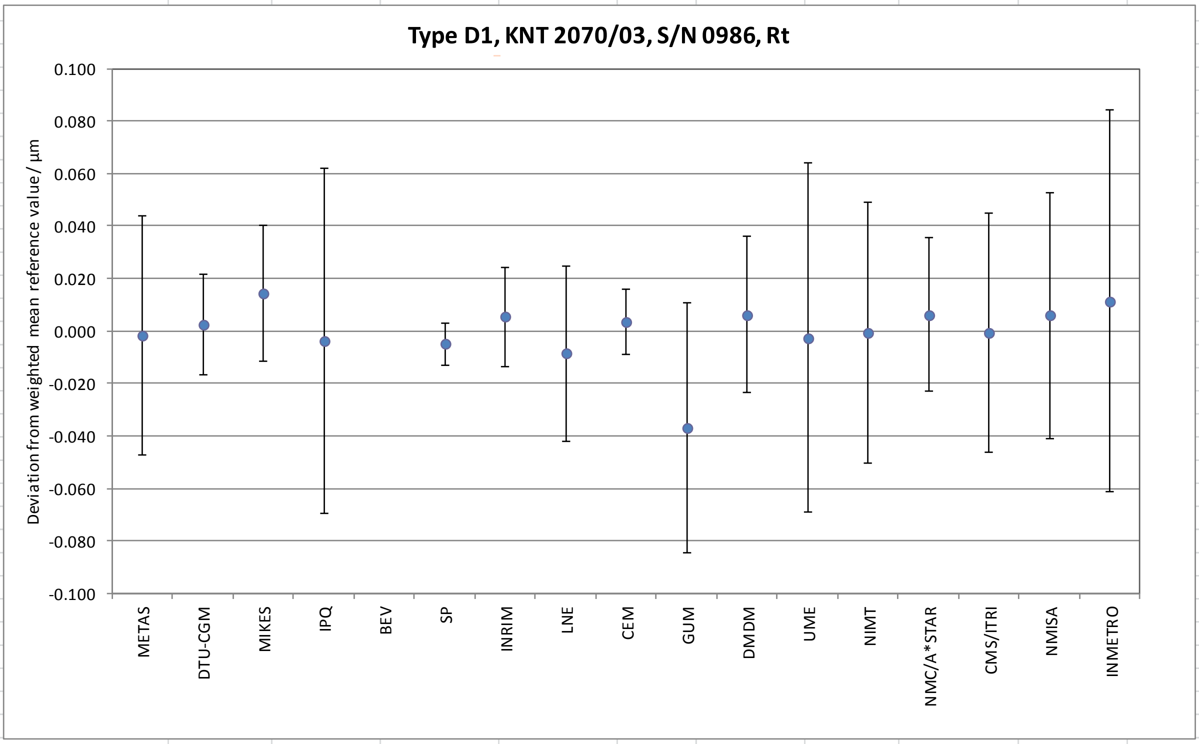
Consistency:		
u_{ext}	0.001	
R_B	0.578	**Birge ok**
Limit	1.315	



select gauge	19	Type D1, KNT 2070/03, S/N 0986, Rt			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	0.442	0.015	0.023	197	1	-0.002	2.00	0.046	0.04	0.02
DTU-CGM	0.446	0.012	0.010	10000	1	0.002	2.00	0.019	0.12	0.09
MIKES	0.458	0.010	0.013	11	1	0.014	2.00	0.026	0.54	0.05
IPQ	0.440	0.012	0.033	138	1	-0.004	2.00	0.066	0.06	0.01
BEV	0.000	0.000	0.000	#NV	0	#NV	#NV	#NV	#NV	0.00
SP	0.439	0.003	0.005	114	1	-0.005	2.00	0.008	0.61	0.36
INRIM	0.449	0.012	0.010	30	1	0.005	2.00	0.019	0.28	0.09
LNE	0.435	0.016	0.017	54	1	-0.009	2.00	0.033	0.26	0.03
CEM	0.447	0.011	0.007	10000	1	0.003	2.00	0.012	0.27	0.19
GUM	0.407	0.006	0.024	19	1	-0.037	2.00	0.048	0.77	0.02
DMDM	0.450	0.016	0.015	10000	1	0.006	2.00	0.030	0.21	0.04
UME	0.441	0.012	0.033	137	1	-0.003	2.00	0.067	0.04	0.01
NIMT	0.443	0.018	0.025	5442	1	-0.001	2.00	0.050	0.01	0.01
NMC/A*STAR	0.450	0.023	0.015	10000	1	0.006	2.00	0.029	0.21	0.04
CMS/ITRI	0.443	0.017	0.023	17	1	-0.001	2.00	0.046	0.01	0.02
NMISA	0.450	0.020	0.024	10000	1	0.006	2.00	0.047	0.13	0.02
INMETRO	0.455	0.032	0.037	10000	1	0.011	2.00	0.073	0.16	0.01

	x_w	$u(x_w)$	ν_{eff}	N - 1	k_{ref}
Reference value	**0.444**	**0.003**	**582**	**15**	**2.00**
C	9.06E-06				

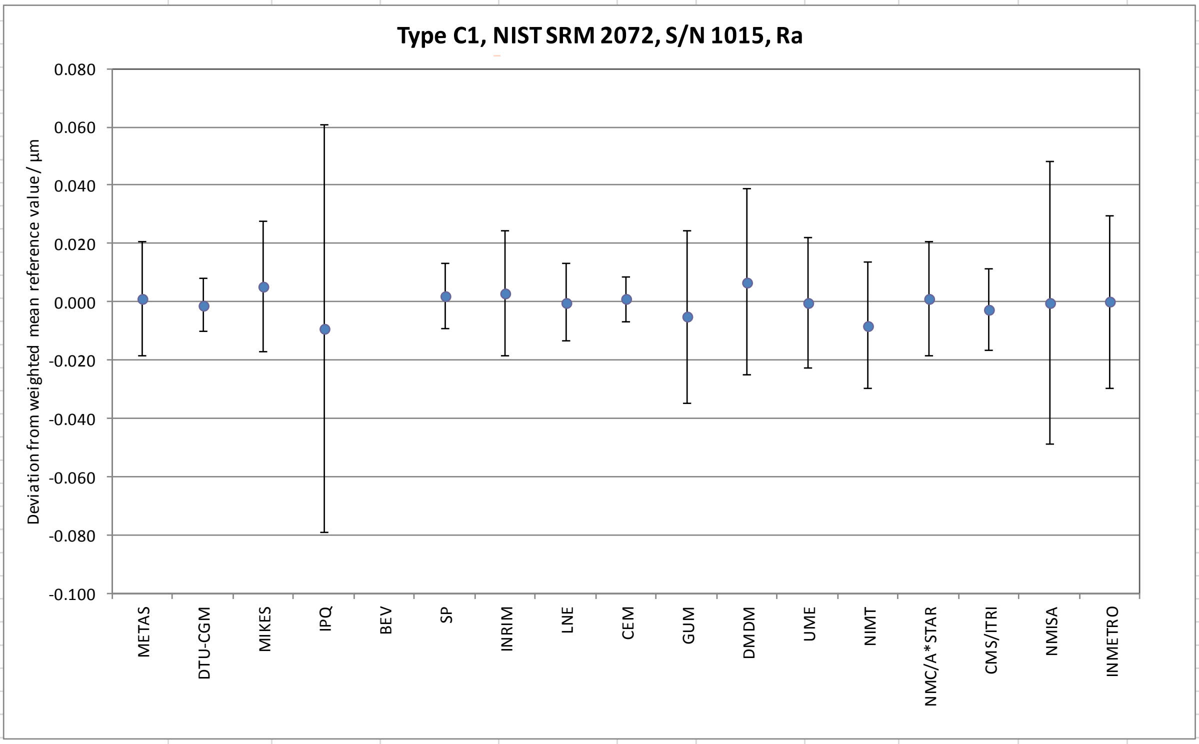
Consistency:		
u_{ext}	0.002	
R_B	0.621	Birge ok
Limit	1.315	



select gauge	20	Type C1, NIST SRM 2072, S/N 1015, Ra			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	$(x_i$-$x_w)$/µm	k	$U(x_i$-$x_{ref})$/µm	E_n	w_i
METAS	1.010	0.003	0.010	180	1	0.001	2.00	0.020	0.04	0.04
DTU-CGM	1.008	0.005	0.005	10000	1	-0.001	2.00	0.009	0.13	0.18
MIKES	1.014	0.004	0.011	11	1	0.005	2.00	0.022	0.24	0.03
IPQ	1.000	0.001	0.035	74	1	-0.009	2.00	0.070	0.13	0.00
BEV	0.000	0.000	0.000	#NV	0	#NV	#NV	#NV	#NV	0.00
SP	1.011	0.001	0.006	225	1	0.002	2.00	0.011	0.16	0.12
INRIM	1.012	0.003	0.011	68	1	0.003	2.00	0.022	0.13	0.04
LNE	1.009	0.003	0.007	23	1	0.000	2.00	0.013	0.01	0.09
CEM	1.010	0.002	0.004	10000	1	0.001	2.00	0.008	0.11	0.23
GUM	1.004	0.001	0.015	40	1	-0.005	2.00	0.030	0.17	0.02
DMDM	1.016	0.002	0.016	10000	1	0.007	2.00	0.032	0.22	0.02
UME	1.009	0.005	0.011	265	1	0.000	2.00	0.022	0.01	0.03
NIMT	1.001	0.002	0.011	363696	1	-0.008	2.00	0.022	0.38	0.04
NMC/A*STAR	1.010	0.002	0.010	10000	1	0.001	2.00	0.020	0.04	0.04
CMS/ITRI	1.006	0.002	0.007	136	1	-0.003	2.00	0.014	0.20	0.08
NMISA	1.009	0.003	0.024	10000	1	0.000	2.00	0.048	0.00	0.01
INMETRO	1.009	0.001	0.015	10000	1	0.000	2.00	0.030	0.00	0.02

	x_w		$u(x_w)$	ν_{eff}	N - 1		k_{ref}
Reference value	**1.009**		**0.002**	**1574**	**15**		**2.00**
C	4.43E-06						

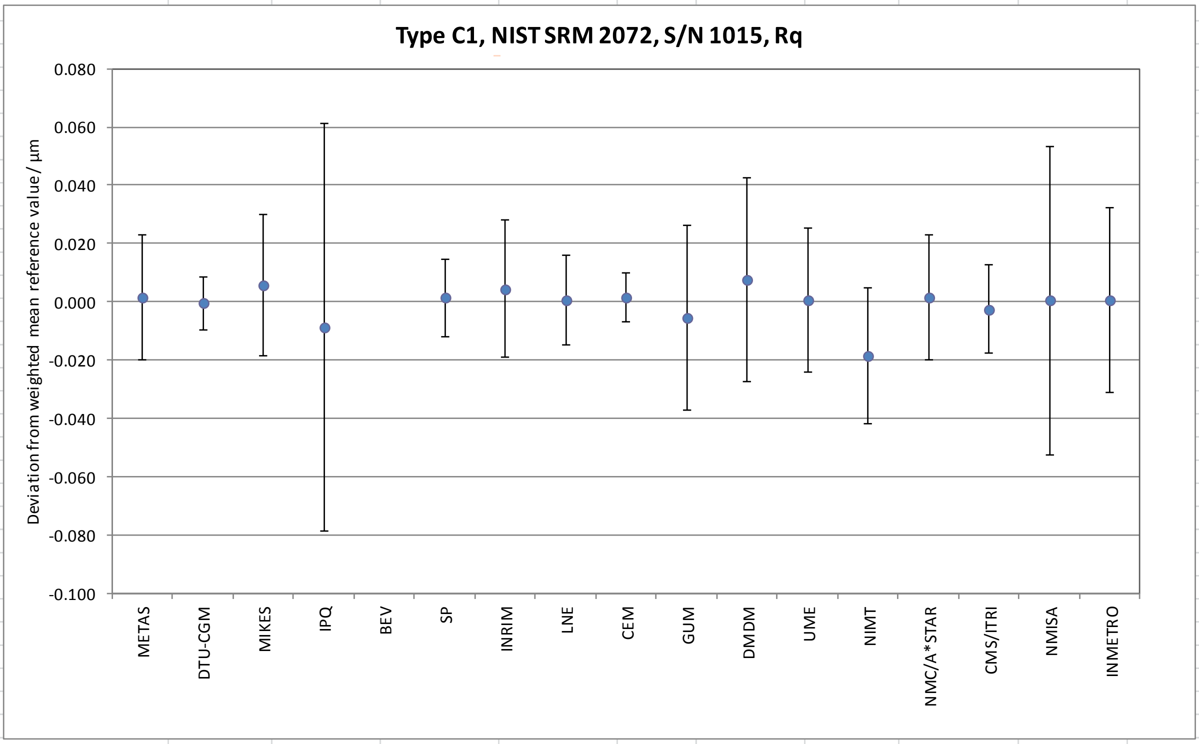
Consistency:		
u_{ext}	0.001	
R_B	0.322	**Birge ok**
Limit	1.315	



select gauge	21	Type C1, NIST SRM 2072, S/N 1015, Rq			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	1.120	0.003	0.011	178	1	0.001	2.00	0.022	0.07	0.04
DTU-CGM	1.118	0.005	0.005	10000	1	-0.001	2.00	0.009	0.06	0.21
MIKES	1.124	0.004	0.012	11	1	0.006	2.00	0.024	0.24	0.03
IPQ	1.110	0.001	0.035	74	1	-0.009	2.00	0.070	0.12	0.00
BEV	0.000	0.000	0.000	#NV	0	#NV	#NV	#NV	#NV	0.00
SP	1.120	0.001	0.007	210	1	0.001	2.00	0.013	0.11	0.11
INRIM	1.123	0.003	0.012	65	1	0.004	2.00	0.024	0.19	0.04
LNE	1.119	0.004	0.008	22	1	0.000	2.00	0.015	0.03	0.08
CEM	1.120	0.003	0.005	10000	1	0.001	2.00	0.008	0.17	0.23
GUM	1.113	0.001	0.016	34	1	-0.006	2.00	0.032	0.18	0.02
DMDM	1.126	0.002	0.018	10000	1	0.007	2.00	0.035	0.21	0.02
UME	1.119	0.005	0.013	265	1	0.000	2.00	0.025	0.02	0.03
NIMT	1.100	0.008	0.012	4398	1	-0.019	2.00	0.023	0.79	0.04
NMC/A*STAR	1.120	0.003	0.011	10000	1	0.001	2.00	0.022	0.07	0.04
CMS/ITRI	1.116	0.003	0.008	130	1	-0.002	2.00	0.015	0.16	0.08
NMISA	1.119	0.003	0.027	10000	1	0.000	2.00	0.053	0.01	0.01
INMETRO	1.119	0.002	0.016	10000	1	0.001	2.00	0.032	0.02	0.02

	x_w	$u(x_w)$	ν_{eff}	$N-1$	k_{ref}
Reference value	**1.119**	**0.002**	**1749**	**15**	**2.00**
C	5.21E-06				

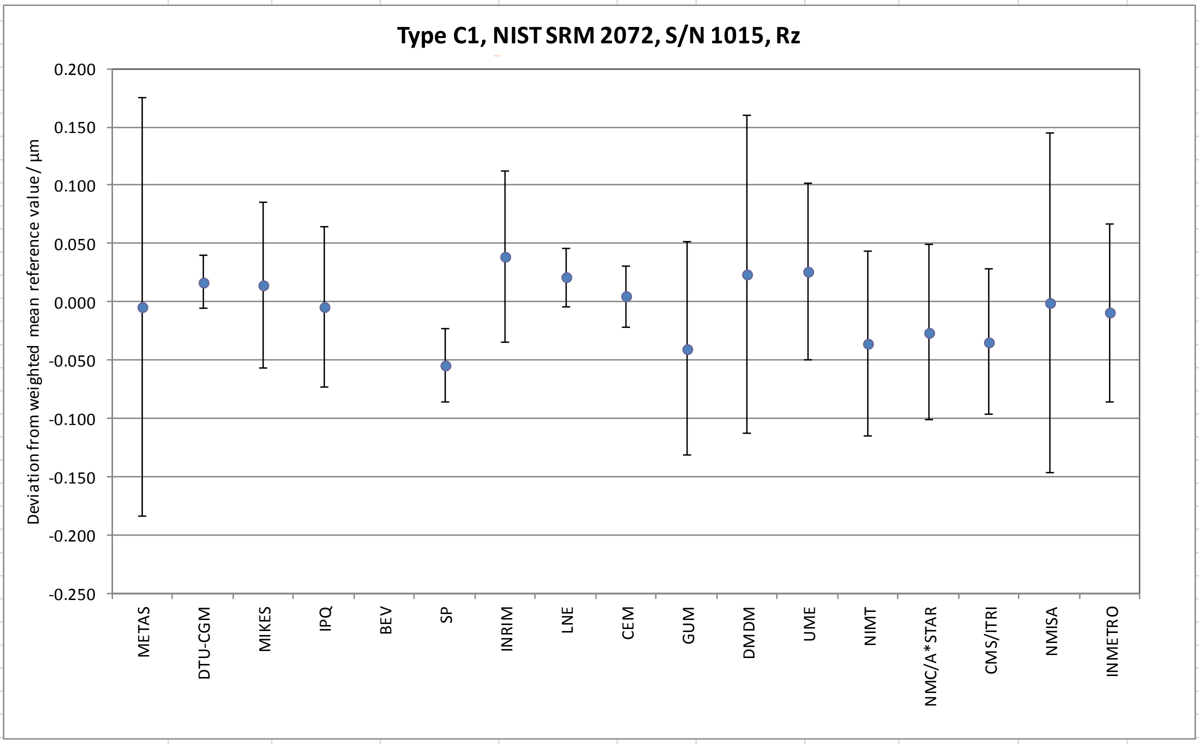
Consistency:		
u_{ext}	0.001	
R_B	0.478	**Birge ok**
Limit	1.315	



select gauge	22	Type C1, NIST SRM 2072, S/N 1015, Rz			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	3.350	0.010	0.090	117	1	-0.004	2.00	0.180	0.02	0.00
DTU-CGM	3.371	0.014	0.013	10000	1	0.017	2.00	0.023	0.74	0.23
MIKES	3.368	0.014	0.036	11	1	0.014	2.00	0.071	0.20	0.03
IPQ	3.350	0.004	0.035	76	1	-0.004	2.00	0.069	0.06	0.03
BEV	0.000	0.000	0.000	#NV	0	#NV	#NV	#NV	#NV	0.00
SP	3.300	0.005	0.017	130	1	-0.054	2.00	0.032	1.71	0.13
INRIM	3.393	0.015	0.037	61	1	0.039	2.00	0.073	0.53	0.03
LNE	3.375	0.020	0.014	28	1	0.021	2.00	0.025	0.83	0.19
CEM	3.359	0.014	0.015	10000	1	0.005	2.00	0.026	0.18	0.18
GUM	3.314	0.005	0.046	13	1	-0.040	2.00	0.091	0.44	0.02
DMDM	3.378	0.012	0.068	10000	1	0.024	2.00	0.136	0.18	0.01
UME	3.380	0.051	0.038	265	1	0.026	2.00	0.076	0.34	0.03
NIMT	3.318	0.016	0.040	32142	1	-0.036	2.00	0.079	0.46	0.02
NMC/A*STAR	3.328	0.014	0.038	15	1	-0.026	2.00	0.075	0.35	0.03
CMS/ITRI	3.320	0.019	0.032	43	1	-0.034	2.00	0.063	0.54	0.04
NMISA	3.353	0.016	0.073	10000	1	-0.001	2.00	0.145	0.01	0.01
INMETRO	3.345	0.007	0.039	10000	1	-0.009	2.00	0.076	0.12	0.03

	x_w		$u(x_w)$	ν_{eff}	N - 1		k_{ref}
Reference value	**3.354**		**0.006**	**585**	**15**		**2.00**
C	3.82E-05						

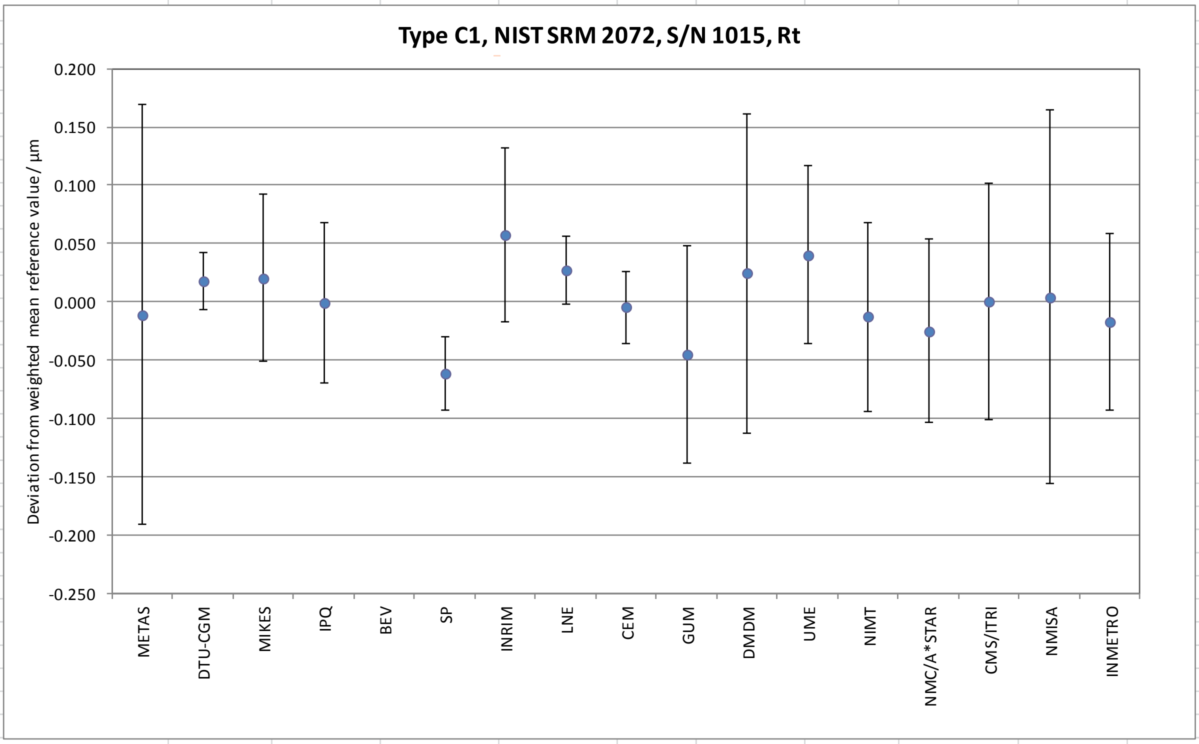
Consistency:		
u_{ext}	0.007	
R_B	1.133	**Birge ok**
Limit	1.315	



select gauge	23	Type C1, NIST SRM 2072, S/N 1015, Rt			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	3.370	0.010	0.090	117	1	-0.011	2.00	0.179	0.06	0.01
DTU-CGM	3.399	0.018	0.014	10000	1	0.018	2.00	0.025	0.74	0.23
MIKES	3.401	0.022	0.036	11	1	0.021	2.00	0.071	0.29	0.03
IPQ	3.380	0.005	0.035	77	1	-0.001	2.00	0.069	0.01	0.04
BEV	0.000	0.000	0.000	#NV	0	#NV	#NV	#NV	#NV	0.00
SP	3.319	0.005	0.017	130	1	-0.062	2.00	0.031	1.98	0.16
INRIM	3.438	0.021	0.038	63	1	0.057	2.00	0.075	0.76	0.03
LNE	3.408	0.024	0.016	37	1	0.027	2.00	0.029	0.94	0.18
CEM	3.376	0.012	0.017	10000	1	-0.005	2.00	0.031	0.15	0.16
GUM	3.336	0.007	0.047	13	1	-0.045	2.00	0.093	0.48	0.02
DMDM	3.405	0.018	0.069	10000	1	0.024	2.00	0.137	0.18	0.01
UME	3.421	0.131	0.039	265	1	0.040	2.00	0.076	0.53	0.03
NIMT	3.368	0.016	0.041	37224	1	-0.013	2.00	0.081	0.16	0.03
NMC/A*STAR	3.356	0.046	0.040	10000	1	-0.025	2.00	0.079	0.31	0.03
CMS/ITRI	3.381	0.040	0.051	17	1	0.000	2.00	0.101	0.00	0.02
NMISA	3.385	0.036	0.080	10000	1	0.004	2.00	0.160	0.03	0.01
INMETRO	3.364	0.009	0.039	10000	1	-0.017	2.00	0.076	0.23	0.03

	x_w	$u(x_w)$	ν_{eff}	$N-1$	k_{ref}
Reference value	**3.381**	**0.007**	**808**	**15**	**2.00**
C	4.53E-05				

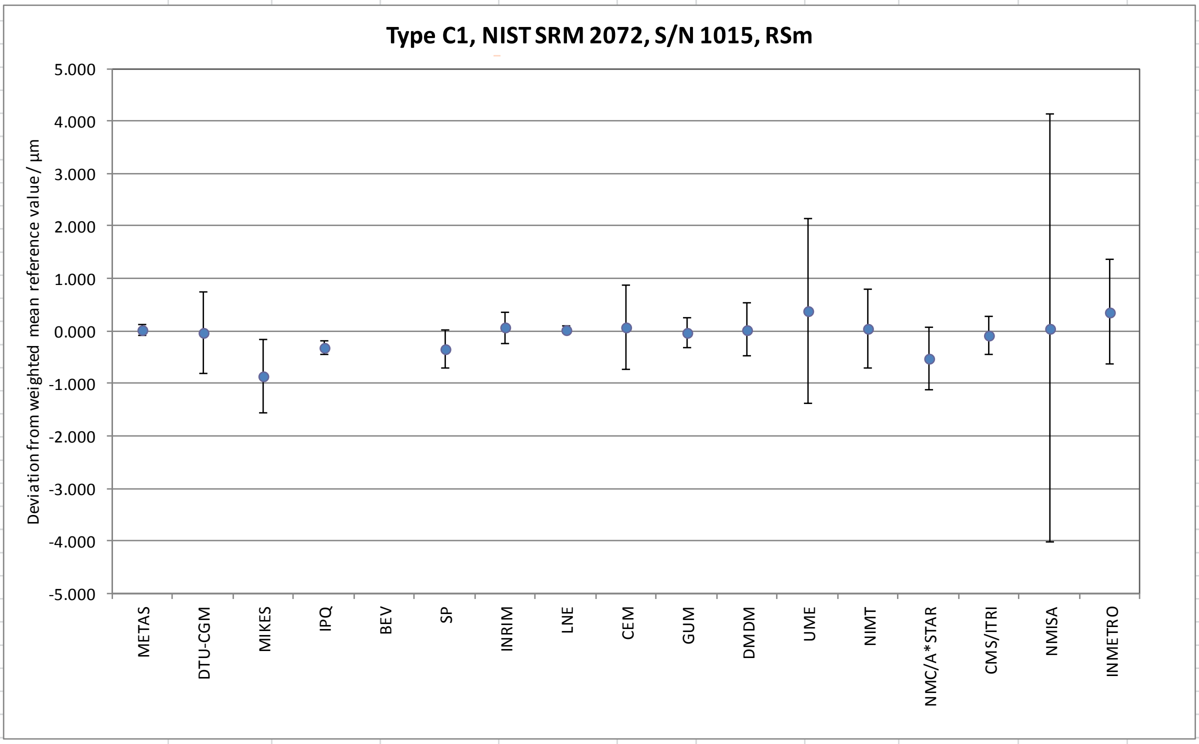
Consistency:		
u_{ext}	0.008	
R_B	1.246	**Birge ok**
Limit	1.315	



select gauge	24	Type C1, NIST SRM 2072, S/N 1015, RSm			use 1 or 0 to in- or exclude		choose: k=2			
Institute	x_i / µm	σ_i / µm	u_i / µm	ν_{eff}	on/off	(x_i-x_w)/µm	k	$U(x_i-x_{ref})$/µm	E_n	w_i
METAS	101.658	0.068	0.063	26	1	0.024	2.00	0.108	0.22	0.26
DTU-CGM	101.600	0.000	0.390	10000	1	-0.034	2.00	0.777	0.04	0.01
MIKES	100.772	0.814	0.350	11	1	-0.862	2.00	0.697	1.24	0.01
IPQ	101.320	0.047	0.059	90	0	-0.314	2.00	0.134	2.34	0.00
BEV	0.000	0.000	0.000	#NV	0	#NV	#NV	#NV	#NV	0.00
SP	101.300	0.200	0.185	11	1	-0.334	2.00	0.364	0.92	0.03
INRIM	101.700	0.110	0.153	50	1	0.066	2.00	0.299	0.22	0.04
LNE	101.662	0.053	0.044	32	1	0.028	2.00	0.060	0.47	0.53
CEM	101.700	0.057	0.400	10000	1	0.066	2.00	0.797	0.08	0.01
GUM	101.600	0.005	0.150	100	1	-0.034	2.00	0.293	0.12	0.05
DMDM	101.664	0.045	0.250	10000	1	0.030	2.00	0.496	0.06	0.02
UME	102.007	0.100	0.883	215	1	0.373	2.00	1.765	0.21	0.00
NIMT	101.680	0.434	0.376	506	1	0.046	2.00	0.749	0.06	0.01
NMC/A*STAR	101.100	0.683	0.300	10000	1	-0.534	2.00	0.597	0.89	0.01
CMS/ITRI	101.553	0.727	0.188	14	1	-0.081	2.00	0.370	0.22	0.03
NMISA	101.688	0.102	2.040	10000	1	0.054	2.00	4.080	0.01	0.00
INMETRO	101.995	0.066	0.500	10000	1	0.361	2.00	0.998	0.36	0.00

	x_w		$u(x_w)$	ν_{eff}	$N-1$		k_{ref}
Reference value	**101.634**		**0.032**	**86**	**14**		**2.00**
C	1.03E-03						

Consistency:		
u_{ext}	0.032	
R_B	1.008	**Birge ok**
Limit	1.325	



8.3 Summary of the E_n values

In Table 5 the E_n values as shown in the tables of section 8.2 (i.e. after exclusion of inconsistent results) are summarized, with $E_n > 1$ highlighted.

Table 5. E_n values of the originally reported results.

Institute	Type A2, KNT 2060/01, S/N 0589606						Type C1, PGN 10, no 682060 5				
	R1, d	R2, d	R3, d	R4, d	R5, d	R6, d	Ra	Rq	Rz	Rt	RSm
METAS	0.01	0.26	0.06	0.09	0.00	0.35	0.18	0.18	0.28	0.18	0.29
DTU-CGM	0.11	0.20	0.14	0.47	0.21	0.45	0.50	0.38	0.49	0.55	0.08
MIKES	0.22	0.16	0.29	0.00	0.02	0.05	0.07	0.13	0.19	0.29	1.11
IPQ	0.11	0.15	0.67	1.15	0.37	0.85	0.07	0.05	0.63	0.49	3.56
BEV	1.84	1.04	1.68	0.92	0.01	0.77	0.50	0.54	1.04	1.23	0.06
SP	0.41	0.12	0.16	0.03	0.05	0.10	0.27	0.29	0.52	0.42	0.18
INRIM	0.55	0.04	0.33	0.06	0.27	0.01	0.07	0.07	0.13	0.11	0.01
LNE	0.14	0.15	0.26	0.21	0.01	0.05	0.31	0.29	0.56	0.48	0.83
CEM	0.41	0.42	0.52	0.32	0.43	0.51	0.02	0.08	0.05	0.06	0.11
GUM	0.24	0.19	0.44	0.07	0.44	0.03	0.75	0.81	0.48	0.22	0.12
DMDM	0.50	0.39	0.17	0.05	0.12	0.01	0.19	0.15	0.12	0.13	0.01
UME	0.10	0.21	0.05	0.20	0.07	0.06	0.12	0.17	0.14	0.12	0.18
NIMT	0.30	0.20	0.69	0.69	0.68	0.65	0.26	0.23	0.01	0.00	0.04
NMC/A*STAR	0.05	0.11	0.07	0.06	0.27	0.09	0.22	0.23	0.43	0.39	2.67
CMS/ITRI	0.61	0.55	0.71	0.53	0.23	0.22	0.02	0.04	0.06	0.05	1.90
NMISA	2.19	1.13	1.07	0.55	0.20	0.20	0.20	0.19	0.25	0.23	0.00
INMETRO	0.18	0.02	0.10	0.24	0.37	0.08	0.07	0.02	0.03	0.05	0.31

Institute	Type D1, S/N 021				Type D1, KNT 2070/03, S/N 0986				Type C1, NIST SRM 2072, S/N 1015				
	Ra	Rq	Rz	Rt	Ra	Rq	Rz	Rt	Ra	Rq	Rz	Rt	RSm
METAS	0.72	0.70	0.59	0.66	0.01	0.09	0.03	0.04	0.04	0.07	0.02	0.06	0.22
DTU-CGM	1.95	2.05	1.62	0.23	0.12	0.16	0.19	0.12	0.13	0.06	0.74	0.74	0.04
MIKES	0.41	0.34	0.27	0.57	0.13	0.16	0.76	0.54	0.24	0.24	0.20	0.29	1.24
IPQ	0.19	0.23	0.19	0.07	0.00	0.07	0.05	0.06	0.13	0.12	0.06	0.01	2.34
BEV													
SP	0.05	0.19	0.21	0.14	0.01	0.01	0.31	0.61	0.16	0.11	1.71	1.98	0.92
INRIM	0.22	0.16	0.40	0.21	0.00	0.03	0.05	0.28	0.13	0.19	0.53	0.76	0.22
LNE	1.13	1.27	0.90	0.95	0.01	0.04	0.21	0.26	0.01	0.03	0.83	0.94	0.47
CEM	0.75	0.76	0.22	0.33	0.17	0.23	0.26	0.27	0.11	0.17	0.18	0.15	0.08
GUM	1.04	1.17	1.63	2.03	0.06	0.08	0.32	0.77	0.17	0.18	0.44	0.48	0.12
DMDM	0.43	0.31	0.01	0.32	0.10	0.17	0.31	0.21	0.22	0.21	0.18	0.18	0.06
UME	1.13	0.87	0.26	0.11	0.11	0.16	0.04	0.04	0.01	0.02	0.34	0.53	0.21
NIMT	0.53	0.66	0.83	0.55	0.00	0.08	0.05	0.01	0.38	0.79	0.46	0.16	0.06
NMC/A*STAR	0.69	0.79	1.40	1.62	0.00	0.08	0.07	0.21	0.04	0.07	0.35	0.31	0.89
CMS/ITRI	1.97	1.87	0.96	0.75	0.01	0.10	0.15	0.01	0.20	0.16	0.54	0.00	0.22
NMISA	0.82	0.93	1.00	0.94	0.18	0.21	0.32	0.13	0.00	0.01	0.01	0.03	0.01
INMETRO	0.24	0.18	0.56	0.38	0.08	0.11	0.43	0.16	0.00	0.02	0.12	0.23	0.36

8.4 Discussion of results

In spite of a relatively large number of inconsistent results, the overall agreement is considered to be satisfactory. A number of inconsistent results can be explained (see section 8.5).

- 32 out of 395 results are not consistent with the reference value, i.e. $E_n > 1$.
- 11 out of 17 laboratories had at least one inconsistent result.
- The largest number (15) of inconsistent results was found on the standard with the least quality, i.e. Rubert D1.

- The degradation of the quality of the standards in the course of the comparison due to surface damages did hardly affect the measurement results. There is no clear trend visible from the first to the last participant, even the last participant achieved excellent results, and the stability measurements made by the pilot were all consistent (see section 6.1).
- Pt values for the type A2 standard were part of the protocol in order to be compatible to the protocol of the preceding comparison EURAMET.L-K8, but do not correspond to the standardized profile depth. They were included in the evaluation spreadsheet of this comparison, but are not part of the draft B report. Therefore no further analysis is carried out on this parameter.

8.5 Changes to results after Draft A report

After sending draft A report, the pilot received three requests to change values or uncertainties:

8.5.1 BEV request from 13.02.2015

I noticed to actually have sent values for the wrong measurand for the type A2 standard. Originally our values are for the central trace (as written on our report) where "the average result together with the standard deviation" was requested. This makes only minor changes to the actual values but the standard deviation is of course much higher (and also the uncertainty).
I have re-evaluated the d parameter according to this.

Attached was a report file with slightly different values and increased uncertainties.

8.5.2 NMISA comment from 06.03.2015 and report from 22.04.2015

I checked the data as the groove stds was far out and did not expect it. The laboratory had a Taylor Hobson Form Talysurf series which was upgraded to a PGI system with a newer version of the same software only months before the inter-comparison. While performing the measurements for the groove standard, Type A2, KNT 2060/01, S/N 0589606, a mistake was made in the analysis of the results. The filter is selected in two places, firstly, the primary filter and in the next instance, instead of no filter in place, we selected the primary filter again.

Our results were thus systematically lower than should be. This came to light when Draft A of the inter-comparison report was published. A re-analysis of all the measurements for the groove depth standard was done and the results are attached.

Attached was a report file with values changed accordingly.

8.5.3 IPQ request from 12.03.2015

I ask if it is possible to consider the following updates: I detect a mistake in the IPQ reported values for the surface roughness standard Type A2, KNT 2060/01, S/N 0589606, R4, d (instead of 2.64 µm it is 2.68 µm). I also made an update of the measurement uncertainty for the parameter RSm of the two standards (Type C1, PGN 10, no 682060 5, RSm and Type C1, NIST SRM 2072, S/N 1015, RSm) adding a new uncertainty component.

Additional information was received from IPQ to justify and support the above mentioned changes. The uncertainties of IPQ for RSm were changed from 77 nm to 321 nm and from 59 nm to 214 nm, respectively, introduced in the spreadsheet *EURAMET.L-K8.2013-revised values.xlsx* and for the analysis in section 8.6.3.

8.6 Comments received after Draft B.1 report

After sending draft B.1 report, the pilot received the following comments:

8.6.1 INMETRO comment from 29.04.2015

I am really sorry, but I made a rough mistake when declaring our measurement uncertainties. Instead of sending you the "uc " uncertainties, I declared the expanded ones (U). All our expanded uncertainties are based in the ones that we have in the KCDB App. C.

For the calibration of depth setting standards they are:
(20+2H) nm; H=d or Pt (in µm)

For the calibration of roughness standards they are:
(10+20P) nm; P=vertical parameters (in µm)

If it would be possible, I ask you, please, to correct our "ui " values in the tables, dividing them by 2, as well plotting the graphs considering it.

This is an obvious mistake. In order to get a more reliable evaluation of the reference values and the degrees of equivalence, the uncertainties of INMETRO were divided by 2, and all data presented in section 8.2 were updated.

8.6.2 NMC/A*STAR comment from 18.05.2015

1) *The supplier in Singapore upgraded the software and we at NMC completed the re-analysis of those raw data captured during the comparison measurement at NMC. It was confirmed that only RSm values were wrongly calculated. ...*
2) *The RSm values of two comparison samples (PNG 10 and NIST SRM2072) were re-calculated and corresponding uncertainties were also slightly changed due to the change of the standard deviation. The results in detail are summarized in attachment, in which new RSm values of two samples are listed. ...*
3) *Since our results (Rz & Rt) for the sample (Type D1, S/N 021) have the En value larger than 1, we need to study the root cause. As requested before, could you please kindly arrange to send the sample for us to do re-measurement at NMC?*

Attached were detailed reports on re-analysis of RSm-values. The following revised values were introduced in the spreadsheet *EURAMET.L-K8.2013-revised values.xlsx* and for the analysis in section 8.7:

Standard	Parameter	Value (µm)	σ (µm)	uc (nm)	veff
PGN 10, no 682060 5,	RSm	199.978	0.058	442	∞
NIST SRM 2072, S/N 1015	RSm	101.663	0.077	228	∞

8.6.3 GUM comment from 19.05.2015

We have once more checked very carefully our results, especially those concerning roughness standard type D1, SN 021. As you know this standard is of the worst quality with scratches and other damages. We have already noted the state of this standard in our first report.

While checking our printed measurements protocol we have noticed a mistake. Instead of giving you the real values of measurement uncertainties we claimed values given in our CMCs. Our measurements protocol prints both values for each roughness parameter. Usually these values are almost the same but at this case they have differed significantly. So if it is possible we would like to ask you to change our uncertainties values concerning Rz and Rt parameters of roughness standard type D1, SN 021. For Rz *parameter we would like to change uncertainty value from 34 nm on 79 nm and for Rt parameter from 36 nm on 114 nm.*

We want also to add that the standard deviation values for Rt and Rz parameters we have measured for this standard exceed the tolerance 3 % value given in the ISO 5436, 5,4 % (0,054 µm) for Rt parameter and 3,5 % (0,035 µm) for Rz parameter.

The above revised uncertainties were introduced in the spreadsheet *EURAMET.L-K8.2013-revised values.xlsx* and for the analysis in section 8.6.3.

8.7 En-values with results revised after draft A and draft B.1 report

The Excel spreadsheet *EURAMET.L-K8.2013-revised values.xlsx* contains values revised for BEV, NMISA and IPQ, according to section 8.5.1, 8.5.2, 8.5.3, 8.6.2 and 8.6.3. The En-values for the parameters subject to changes were calculated again and are summarized in Table 6. Values in red or their uncertainties were changed.

It has to be noted, that this analysis is in fact outside the scope of the key comparison, since the rules for CIPM MRA comparisons do not allow to change any results after draft A report. Therefore the key comparison reference values and the degrees of equivalence resulting from this comparison are those reported in the tables of section 8.2, the E_n values those of Table 5 in section 8.3. The partly substantial changes of the values from BEV and NMISA for the type A2 standard have an influence on the reference values and thus also to the E_n values of the other laboratories. These changes are certainly justified, since the original values refer to the wrong measurand, and one might argue, that the reference values after these changes are more reliable. For this reason, it is worthwhile to show the impact of the revised results on the E_n values, although, as stated above, outside the scope of the key comparison.

Table 6. E_n values of the revised results.

	Type A2, KNT 2060/01, S/N 0589606						Type C1, PGN 10, no 682060 5				
Institute	R1, d	R2, d	R3, d	R4, d	R5, d	R6, d	Ra	Rq	Rz	Rt	RSm
METAS	0.07	0.28	0.16	0.23	0.05	0.16	0.18	0.18	0.28	0.18	0.19
DTU-CGM	0.16	0.22	0.22	0.39	0.23	0.40	0.50	0.38	0.49	0.55	0.07
MIKES	0.15	0.20	0.18	0.09	0.04	0.01	0.07	0.13	0.19	0.29	1.10
IPQ	0.09	0.14	0.64	0.45	0.38	0.79	0.07	0.05	0.63	0.49	0.98
BEV	0.86	0.43	0.92	0.35	0.24	0.53	0.50	0.54	1.04	1.23	0.03
SP	0.31	0.07	0.03	0.10	0.03	0.16	0.27	0.29	0.52	0.42	0.17
INRIM	0.21	0.01	0.14	0.13	0.24	0.10	0.07	0.07	0.13	0.11	0.02
LNE	0.21	0.12	0.18	0.13	0.00	0.00	0.31	0.29	0.56	0.48	0.75
CEM	0.18	0.31	0.22	0.01	0.54	0.34	0.02	0.08	0.05	0.06	0.09
GUM	0.28	0.21	0.52	0.03	0.41	0.18	0.75	0.81	0.48	0.22	0.16
DMDM	0.57	0.43	0.24	0.02	0.10	0.05	0.19	0.15	0.12	0.13	0.00
UME	0.19	0.25	0.09	0.08	0.04	0.01	0.12	0.17	0.14	0.12	0.18
NIMT	0.23	0.17	0.59	0.63	0.70	0.61	0.26	0.23	0.01	0.00	0.05
NMC/A*STAR	0.01	0.14	0.04	0.07	0.24	0.22	0.22	0.23	0.43	0.39	0.03
CMS/ITRI	0.39	0.45	0.47	0.38	0.26	0.13	0.02	0.04	0.06	0.05	1.94
NMISA	0.34	0.24	0.14	0.04	0.09	0.00	0.20	0.19	0.25	0.23	0.00
INMETRO	0.23	0.05	0.00	0.36	0.34	0.07	0.07	0.02	0.03	0.05	0.32

Institute	Type D1, S/N 021				Type D1, KNT 2070/03, S/N 0986				Type C1, NIST SRM 2072, S/N 1015				
	Ra	Rq	Rz	Rt	Ra	Rq	Rz	Rt	Ra	Rq	Rz	Rt	RSm
METAS	0.72	0.70	0.60	0.67	0.01	0.09	0.03	0.04	0.04	0.07	0.02	0.06	0.23
DTU-CGM	1.95	2.05	1.61	0.24	0.12	0.16	0.19	0.12	0.13	0.06	0.74	0.74	0.04
MIKES	0.41	0.34	0.29	0.60	0.13	0.16	0.76	0.54	0.24	0.24	0.20	0.29	1.24
IPQ	0.19	0.23	0.18	0.07	0.00	0.07	0.05	0.06	0.13	0.12	0.06	0.01	0.74
BEV													
SP	0.05	0.19	0.24	0.11	0.01	0.01	0.31	0.61	0.16	0.11	1.71	1.98	0.91
INRIM	0.22	0.16	0.41	0.21	0.00	0.03	0.05	0.28	0.13	0.19	0.53	0.76	0.22
LNE	1.13	1.27	0.87	0.93	0.01	0.04	0.21	0.26	0.01	0.03	0.83	0.94	0.47
CEM	0.75	0.76	0.23	0.34	0.17	0.23	0.26	0.27	0.11	0.17	0.18	0.15	0.08
GUM	1.04	1.17	0.71	0.66	0.06	0.08	0.32	0.77	0.17	0.18	0.44	0.48	0.11
DMDM	0.43	0.31	0.02	0.30	0.10	0.17	0.31	0.21	0.22	0.21	0.18	0.18	0.06
UME	1.13	0.87	0.25	0.12	0.11	0.16	0.04	0.04	0.01	0.02	0.34	0.53	0.21
NIMT	0.53	0.66	0.82	0.55	0.00	0.08	0.05	0.01	0.38	0.79	0.46	0.16	0.06
NMC/A*STAR	0.69	0.79	1.42	1.63	0.00	0.08	0.07	0.21	0.04	0.07	0.35	0.31	0.07
CMS/ITRI	1.97	1.87	0.96	0.74	0.01	0.10	0.15	0.01	0.20	0.16	0.54	0.00	0.22
NMISA	0.82	0.93	1.01	0.95	0.18	0.21	0.32	0.13	0.00	0.01	0.01	0.03	0.01
INMETRO	0.24	0.18	0.58	0.38	0.08	0.11	0.43	0.16	0.00	0.02	0.12	0.23	0.36

8.8 Linking of result to other comparisons

The comparison followed the protocol of the former comparison EURAMET.L-K8.2009 as closely as possible. Also in the comparison APMP.L-K8.2008 similar artefacts were used. To what extent the three comparisons can be linked to each other, and whether this brings any added value, needs to be investigated by the CCL Task Group on comparison linking (TG-L) once the final reports of all three comparisons are available.

9 Softgauges

9.1 Description of the files

Two softgauges with type F1 reference data were sent to the participants. The files *METAS_Aperiodic* and *METAS_Periodic* were available in *.smd and *.prf format, the former according to ISO 5436-2, the latter to be compatible with Taylor Hobson Ultra software. The conditions for evaluation and the parameters to be determined are described in sections 4.6 and 5.4.

The aperiodic softgauge was produced from a measurement on a fine aperiodic roughness standard. The periodic softgauge was numerically generated from the superposition of two periodic waves with 100 µm and 800 µm wavelength and 100 nm and 20 nm amplitude, respectively, and adding some random noise with 5 nm amplitude.

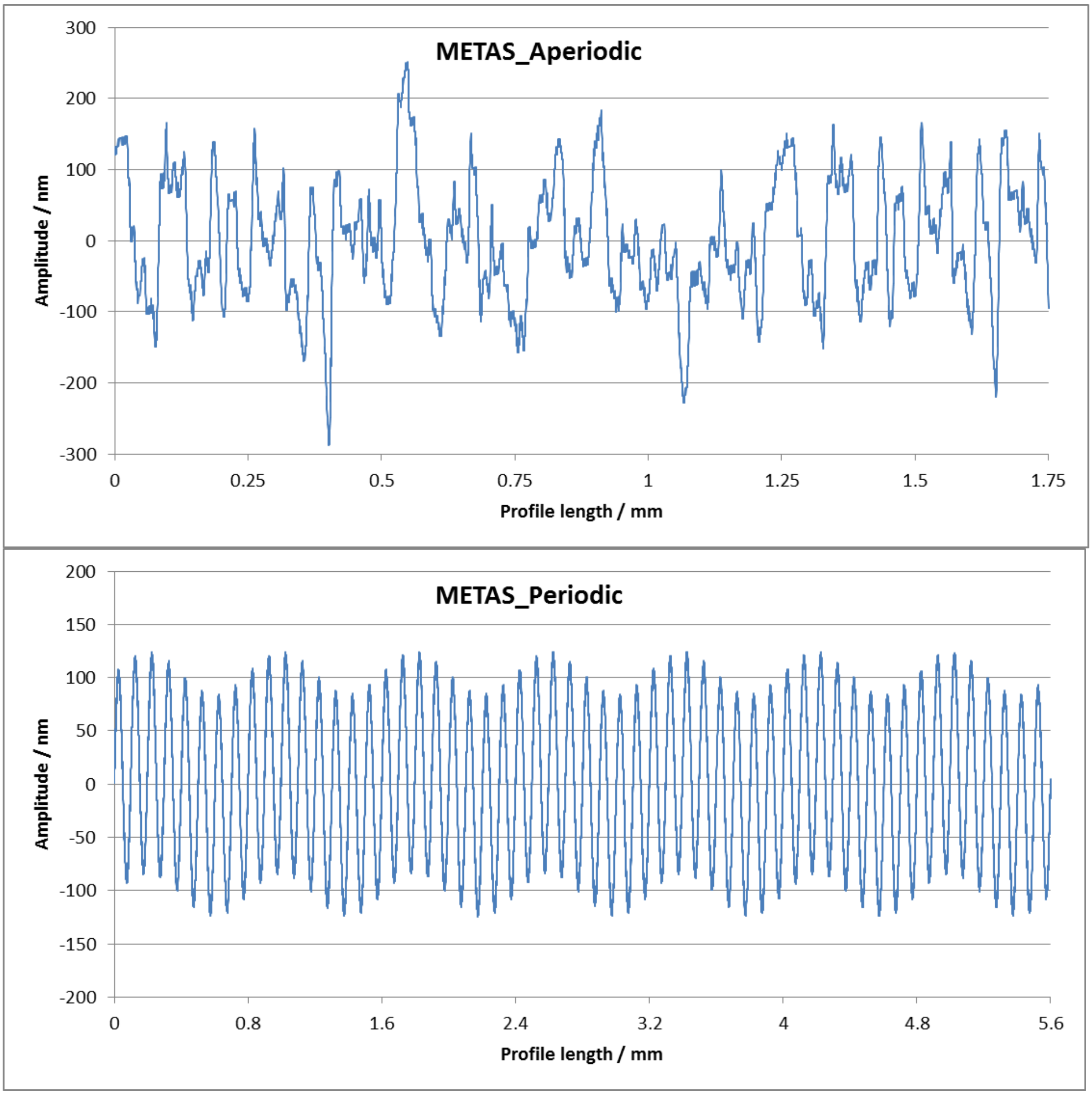


Figure 9. Profiles of the two softgauges.

9.2 Results of participants

Table 7. Results reported for METAS_Periodic.smd with mean and standard deviation (UME excluded from mean and standard deviation).

	Ra (µm)	Rq (µm)	Rz (µm)	Rt (µm)	RSm (µm)
METAS	0.06376	0.071	0.2217	0.2234	99.815
DTU_1	0.064	0.071	0.221	0.226	100.0
DTU_2	0.064	0.071	0.222	0.223	100.0
MIKES	0.0637	0.071	0.2218	0.2235	100
SP	0.0638	0.071	0.2216	0.2234	100
LNE	0.06376512	0.07100243	0.22161773	0.2232598	100.092183
INRIM_1	0.0638	0.071	0.2217	0.2234	99.91
INRIM_2	0.0638	0.071	0.2217	0.2234	99.96
UME	0.064	0.071	0.229	0.229	100.061
NIMT	0.0638	0.071	0.2217	0.2234	-
CEM	0.063765	0.071002	0.221618	0.22326	100.092
NMC/A*STAR	0.0637	0.071	0.2218	0.2235	100
CMS	0.063767	0.071004	0.221688	0.223412	99.871429
INMETRO	0.0638	0.071	0.2216	0.2234	100.2837
Mean	0.063804	0.071001	0.22166	0.22356	100.002
StdDev	0.000093	0.000001	0.00023	0.00074	0.120

Table 8. Results reported for METAS_Aperiodic.smd with mean and standard deviation (UME excluded from mean and standard deviation).

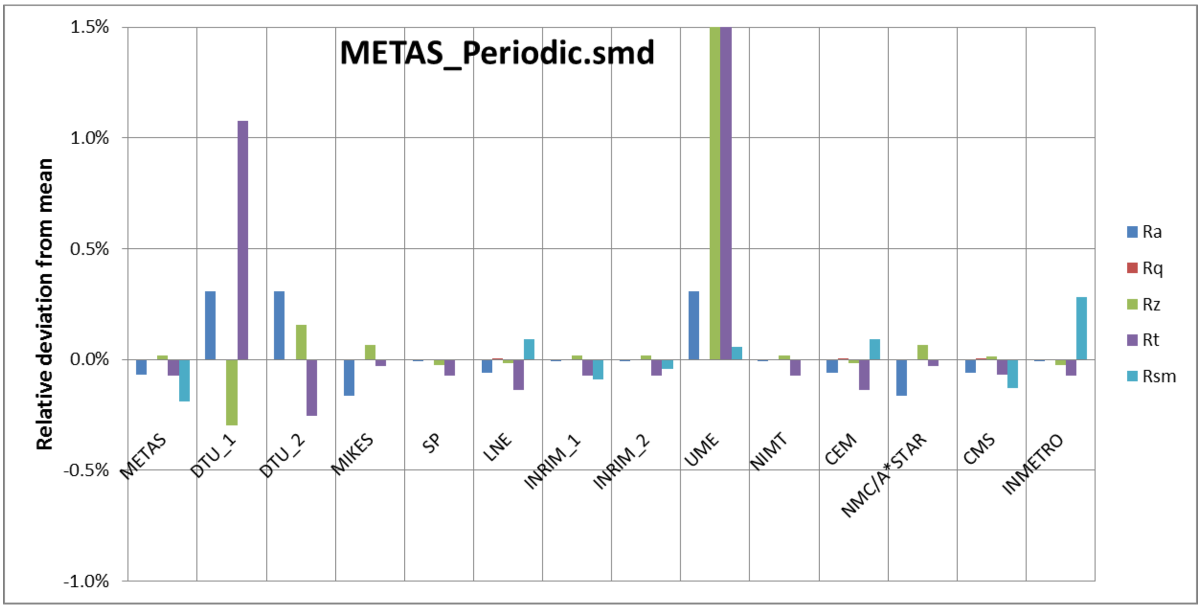
	Ra (µm)	Rq (µm)	Rz (µm)	Rt (µm)	Rsk
METAS	0.059883	0.074573	0.327789	0.456508	-0.033
DTU_1	0.06	0.075	0.328	0.457	-0.022
DTU_2	0.060	0.075	0.328	0.456	-0.033
MIKES	0.0595	0.0742	0.3276	0.4561	-0.0167
SP	0.0597	0.0744	0.3274	0.456	-0.0188
LNE	0.0598589	0.07393566	0.32751571	0.4563038	-0.141065
INRIM_1	0.0597	0.0744	0.3274	0.4561	-0.0186
INRIM_2	0.0599	0.0746	0.3278	0.4564	-0.0334
UME	0.061	0.075	0.337	0.459	-0.029
NIMT	0.0599	0.074	0.3278	0.4565	-0.1641
CEM	0.059859	0.073936	0.327516	0.456304	-0.141
NMC/A*STAR	0.0595	0.0742	0.3276	0.4561	-0.0186
CMS	0.059979	0.073939	0.327796	0.455334	-0.135478
INMETRO	0.0597	0.0744	0.3274	0.4561	-0.0186
Mean	0.05981	0.07435	0.32766	0.45621	-0.061
StdDev	0.00017	0.00037	0.00022	0.00038	0.059

Table 9. Software used by participating laboratories for evaluating the softgauges.

Institute	Software
METAS	METAS developed LabView software
DTU_1	Home made RCS4G
DTU_2	RoughnessPro by Image Metrology
MIKES	Taylor Hobson Ultra, Version n° : 5.14.9.70
SP	Taylor Hobson Ultra, Version n°: 4.6.8

LNE	Mountains Premium, Version n° : 6.2.6845
INRIM_1	Taylor Hobson Ultra V5.1.14
INRIM_2	RoughnessPro by Image Metrology
UME	Mahr Perthometer Concept, Version 6.3
NIMT	home made
CEM	Mountains Map, Version n° : 6.0.0.5727
NMC/A*STAR	Taylor Hobson Ultra, Version n° : 5.21.9.36
CMS	CMS_Surf.exe, version 2.1.1
INMETRO	Taylor Hobson Ultra, Version n° : 5.23.12.97

9.3 Graphical representation of deviations from the mean



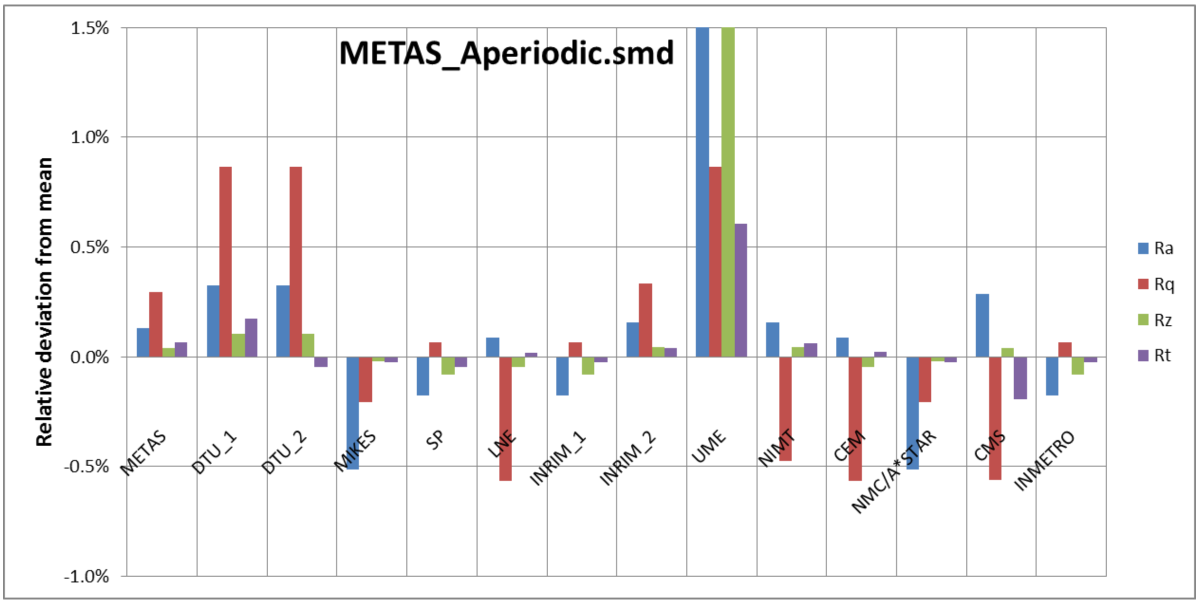
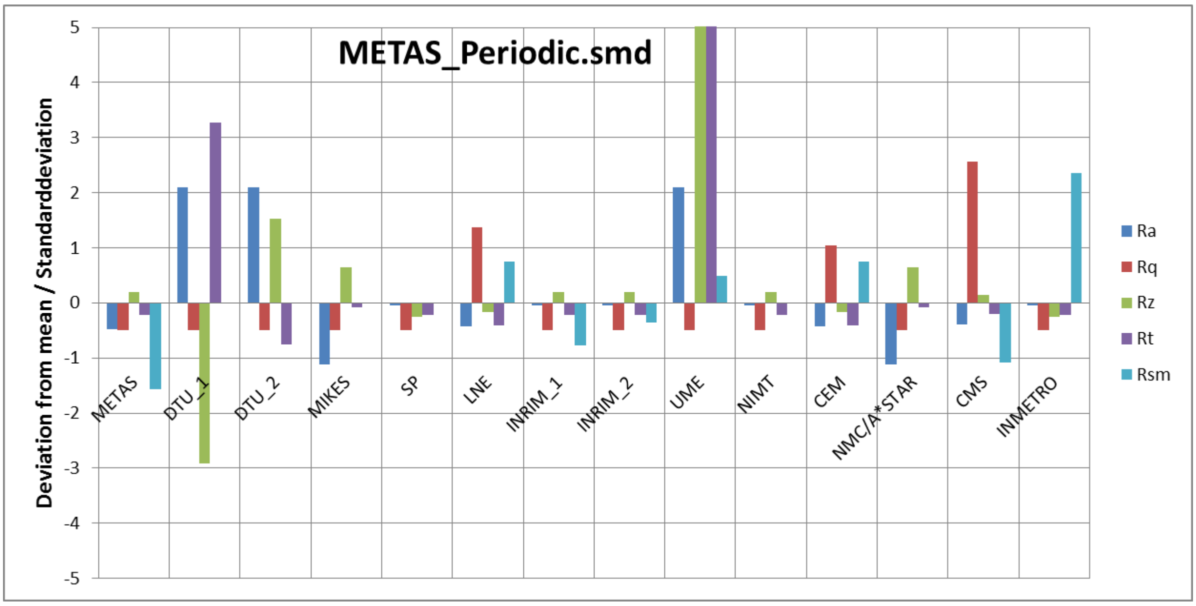


Figure 10. Relative deviation from mean.



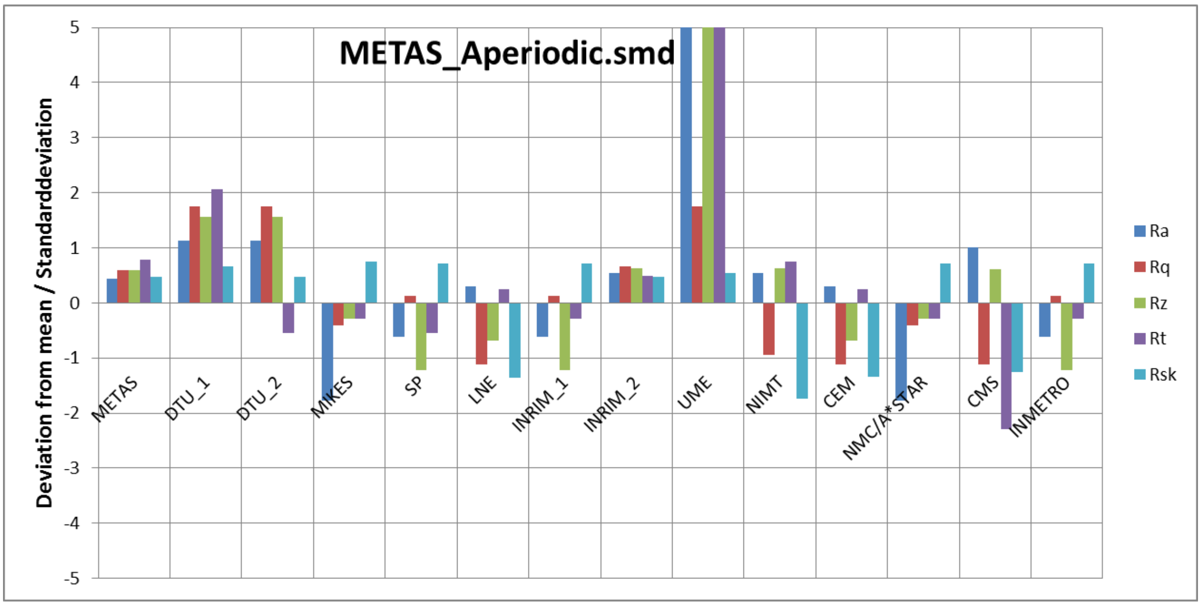


Figure 11. Deviation from mean in terms of multiples of the standard deviation.

10 Conclusions

After the first corrective actions and some corrections taken by a few of the participating laboratories, the number of E_n values > 1 could be reduced from 32 to 20 out of a total of 395 individual results, which corresponds to 5 % and can statistically be expected, since the E_n criterion is based on a 95 % confidence interval. On good quality standards, such as the Halle A2 depth setting or the Halle D1 fine roughness standards, all results were in good agreement. 13 of the values with E_n > 1 were observed on the Rubert D1 standard, which shows clear signs of use and damage and the largest standard deviations for the peak parameters, i.e. between 5 % and 10 %.

Regarding the softgauges, an analysis is much more difficult, since no uncertainties were quoted and reference values are not available (the mean of the reported results cannot be considered to be a reference value). Most of the results agree within roughly 0.2 % of the value. This can hardly be explained by numerical computation accuracy and a more detailed study needs to be carried out, taking into account the results of similar comparisons on other softgauges.

11 References

[1] Calibration of surface roughness standards , http://kcdb.bipm.org/appendixB/KCDB_ApB_info.asp?cmp_idy=986&cmp_cod=EURAMET.L-K8&prov=exalead

[2] ISO 5436-1:2000, Geometrical Product Specifications (GPS) - Surface texture: Profile method; Measurement standards - Part 1: Material measures

[3] ISO 4287:1997, Geometrical Product Specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters

12 Appendix: Equipment of the participating laboratories

Institute	Instrument	Stylus	Sampling spacing	Meas. speed	Meas. force
METAS	Taylor Hobson Talysurf FTS 120L	TH, 2 µm, 90°	0.25 µm	0.5 mm / s	0.72 mN
DTU-CGM	Taylor Hobson Talysurf 5-120	TH, 2 µm, 70°	0.1 µm	0.1 mm / s	-
MIKES	Taylor Hobson Form Talysurf	TH, 2 µm	0.25 µm	0.5 mm / s	1.2 mN
IPQ	Mahr Pethometer S8P	Mahr, 2 µm, 90°	0.5 µm	0.5 mm / s	0.4 mN
BEV	SIOS NMM-1 with laser focus sensor (LFS)	SIOS LFS, integrated with NMM-1	0.1 µm	2 µm / s	0 (optical)
SP	Taylor Hobson Form Talysurf 120	TH, 2 µm, 90°	0.25 µm	0.5 mm / s	<0.70 mN
INRIM	Taylor Hobson Talystep 1 Taylor Hobson Form Talysurf II	TH, 2.5 µm, 90° TH, 2 µm, 90°	0.35 µm 0.25 µm	25 µm/s 0.5 mm / s	40 .. 100 µm 1 mN
LNE	Homemade 3D profilometer with 3 laser interferometers	TH, 2 µm, 90°	0.1 µm		<1 mN
CEM	KLA-Tencor P-6 Stylus Profiler	KLA-Tencor, 2 µm, 60°	0.1 .. 0.2 µm	20 .. 200 µm / s	0.02 .. 0.1 mN
GUM	Taylor Hobson Form Talysurf II	TH, 2 µm	0.25 µm	0.5 mm / s	0.7 mN
DMDM	Mahr MarSurf UD 120	Mahr, 2 µm, 60°	0.25 µm	0.1 mm / s	0.7 mN
UME	Mahr Perthometer Concept	Mahr, 2 µm, 90°	0.04 .. 0.5 µm	0.1 .. 0.5 mm / s	0.7 mN
NIMT	Kosaka ET 4000	Kosaka, 2 µm, 60°	0.5 µm	0.05 mm / s	0.4 mN
NMC/A*STAR	Taylor Hobson PGI 2540	TH, 2 µm, 60°	0.125 µm	0.1 .. 0.25 mm / s	0.75 mN
CMS/ITRI	Kosaka ET-4100 SURFCORDER	Kosaka, 2 µm, 60°	0.025 .. 0.35 µm	0.02 .. 0.1 mm / s	0.05 mN
NMISA	Taylor Hobson Form Talysurf PGI 840	TH, 2 µm, 60°	0.125 µm	1 mm / s	1 mN
INMETRO	Taylor Hobson PGI 830	TH, 2 µm, 90°	0.125 µm	0.25 mm / s	1 mN

13 Appendix: Traceability of the participating laboratories

Institute	Vertical measurement traceability	NMI	Transverse measurement traceability	NMI
METAS	Reference sphere	METAS	Glass line scale artifact	METAS
DTU-CGM	6 step Halle standard	PTB	reference grid	NPL
MIKES	Calibration ball	MIKES	Type C1 Normals, calibrated with metrol. AFM	MIKES
IPQ	Surface texture standard type A1	CEM	Surface texture standard type D	IPQ
BEV	Laser interferometer	BEV	Laser interferometer	BEV
SP	Gauge blocks	SP	Invar line scale	SP
INRIM	Talystep 1: Precision displacement actuator Formtalysurf: precision ceramic ball	INRIM	stage micrometer and/or gratings	INRIM
LNE	Laser interferometer	LNE	Laser interferometer	LNE
CEM	Step height standards, calibrated by laser interferometer (on the NMM SIOS)	CEM	Line scale and grids, calibrated by laser interferometer (on the NMM SIOS)	CEM
GUM	Halle, type A2	PTB	Roughness standards type A2	PTB
DMDM	Roughness standard	HMI/FSB	Laser interferometer	DMDM
UME	Piezo transducer's actuator	UME	Type C standard PGN-3, calibrated by laser interferometer	UME
NIMT	Type A1 standard calibrated by laser interference microscope	NIMT	Standard glass scale calibrated by line scale interferometer	NIMT
NMC/A*STAR	Hemisphere	NMC/A*STAR	Hemisphere	NMC/A*STAR
CMS/ITRI	Step height standard	CMS/ITRI	Line scale standard	CMS/ITRI
NMISA	Reference sphere	NMISA	Reference sphere	NMISA
INMETRO	6 step height Halle	PTB	Line scale standard	INMETRO

14 Appendix: CMCs as declared by the participating laboratories in the CIPM MRA

CCL service categories related to surface texture:

5.1.1 (groove) depth (step height) standard (e.g. ISO 5436-1 Type A).
5.1.2 tip-condition standard (e.g. ISO 5436-1 Type B).
5.1.3 spacing standard (e.g. ISO 5436-1 Type C).
5.1.4 roughness standard (e.g. ISO 5436-1 Type D).
5.1.5 profile coordinate standard (e.g. ISO 5436-1 Type E).
5.1.6 softgauge standard (reference software data set).

NMI Service Id	CCL service category	Parameters	Range		$U(k = 2)$ (nm)	Remarks
			Min.	Max.		
METAS#44	5.1.1	*d*	0.1 µm	1000 µm	Q[10, 0.2 *d*], *d* in µm	-
METAS#46	5.1.3	*Ra, Rq*	0.01 µm	100 µm	Q[4, 16 *Ra*], *Ra* in µm	-
		Rp, Rv, Rz, Rt			Q[30, 40 *Rp*], *Rp* in µm	-
METAS#47	5.1.4	*Ra, Rq*	0.01 µm	20 µm	Q[4, 30 *Ra*], *Ra* in µm	-
		Rp, Rv, Rz, Rt			Q[30, 60 *Rp*], *Rp* in µm	-
DTU/CGM	-	-	-	-	-	-
MIKES#41	5.1.1	*S*	0 µm	400 µm	Q[10, 70 *S*], S in µm	
MIKES#42	5.1.3 5.1.4	*S*	0 µm	400 µm	Q[10, 70 *S*], *S* in µm	
IPQ#101.40	5.1.3	*Ra*	0.1 µm	10 µm	Q[50, 30 *Ra*], *Ra* in µm	-
		Rz, Rp, Rv, Rt			Q[50, 30 *Rz*], *Rz* in µm	-
IPQ#101.40	5.1.4	*Ra*	0.1 µm	20 µm	Q[50, 30 *Ra*], *Ra* in µm	-
		Rz, Rp, Rv, Rt			Q[50, 30 *Rz*], *Rz* in µm	-
BEV#25	5.1.1	*d*	0.01 µm	10 µm	Q[5, 10 *d*], *d* in µm	different technique
SP#36	5.1.1	*H*	0.05 µm	1000 µm	Q[5, 20 *H*], *H* in µm	-
SP#37	5.1.3	*Ra, Rq*	0.01 µm	20 µm	Q[5, 20 *Ra*], *Ra* in µm	-
		Rz, Rt			Q[10, 30 *Rz*], *Rz* in µm	-

NMI Service Id	CCL service category	Parameters	Range		$U(k = 2)$ (nm)	Remarks
			Min.	Max.		
INRIM#24	5.1.1	*d*	0.01 µm	15 µm	Q[1, 4.7 *d*], *d* in µm	
INRIM#33	5.1.3	*Ra*	0.1 µm	20 µm	Q[10, 30 *Ra*], *Ra* in µm	-
		Rz, Rp, Rv, Rt			Q[20, 50 *Rz*], *Rz* in µm	-
		RSm	50 µm	500 µm	0.5 µm	
INRIM#34	5.1.4	*Ra*	0.1 µm	20 µm	Q[10, 30 *Ra*], *Ra* in µm	-
		Rz, Rp, Rv, Rt			Q[20, 50 *Rz*], *Rz* in µm	-
LNE	-	-	-	-	-	-
CEM#33b	5.1.1	*H*	0.01 µm	15 µm	Q[2, 20 *H*], *H* in µm	-
CEM#34	5.1.4	*Ra*	0.01 µm	15 µm	Q[9, 30 *Ra*], *Ra* in µm	-
		Rz			Q[14, 40 *Rz*], *Rz* in µm	-
GUM#26	5.1.1	*Pt, d*	0.1 µm	100 µm	Q[30, 0.5 *d*], *d* in µm	-
GUM#27	5.1.3	*Ra, Rq*	0.05 µm	30 µm	Q[15, 25 *Ra*], *Ra* in µm	-
		Rz, Rt			Q[40, 50 *Rp*], *Rp* in µm	-
GUM#28	5.1.4	*Ra, Rq*	0.05 µm	30 µm	Q[15, 30 *Ra*], *Ra* in µm	-
		Rz, Rt			Q[40, 60 *Rp*], *Rp* in µm	-
DMDM	-	-	-	-	-	-
UME#34	5.1.1	*d*	0.01 µm	750 µm	Q[18, 30 *d*], *d* in µm	-
UME#35	5.1.3	*Ra, Rq, Rz, Rp, Rt, Rv*	0.01 µm	20 µm	Q[10, 40 *Ra*], *Ra* in µm	-
UME#36	5.1.4	*Ra, Rq, Rz, Rp, Rt, Rv, Rpk, Rvk*, Mr_1, Mr_2	0.01 µm	20 µm	Q[10, 40 *Rz*], *Rz* in µm	-
NIMT#08060-10501	5.1.1	*d*	25 nm	32 µm	Q[6.6, 12 *d*], *d* in µm	-
NIMT#08060-10601	5.1.3 5.1.4	*Ra*	25 nm	32 µm	Q[10, 12 *Ra*], *Ra* in µm	-
		Rz			Q[18, 17 *Rz*], *Rz* in µm	-
NMC/A*STAR #D049	5.1.4	ISO roughness parameters (eg. *Ra*)	0.1 µm	10 µm	Q[36, 30 *Ra*], *Ra* in µm	-

NMI Service Id	CCL service category	Parameters	Range		$U(k = 2)$ (nm)	Remarks
			Min.	Max.		
CMS#D21	5.1.1	*D*	0.01 µm	50 µm	Q[5, 3.2 *D*], *D* in µm	
CMS#D13	5.1.3 5.1.4	*Ra, Rq*	0.01 µm	20 µm	Q[5, 13 *R*], *R* in µm	
NMISA#	5.1.1	*d*	0.01 µm	3000 µm	Q[4, 20 *d*], *d* in µm	
NMISA#	5.1.3 5.1.4	*Ra*	0.01 µm	100 µm	Q[10, 30 *Ra*], *Ra* in µm	
INMETRO#27	5.1.1	*H*	0.05 µm	20 µm	20 + 2 *H*, *H* in µm	
INMETRO#29	5.1.3 5.1.4	*Ra, Rz, Rmax*	0.01 µm	20 µm	10 + 20 *Ra*, *Ra* in µm	